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OF

The Royal Society

OF

Western Australia.

Vol. XVIII.
1931-32.

The Authors of Papers are alone responsible for the statements
and
the opinions expressed therein.

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THE ROYAL SOCIETY OF WESTERN AUSTRALIA.

OFFICERS AND COUNCIL, 1931-32.

CONTENTS.

VOLUME XVIII.

ANNUAL REPORT OF THE COUNCIL FOR YEAR ENDING 30th JUNE, 1932.

LADIES AND GENTLEMEN,

Your Council begs to submit the following report for the year ending 30th June, 1932.

MEMBERSHIP.

On 30th June, 1932, 203 members were on the roll, of whom nine are honorary members, five corresponding members, 114 ordinary members, 59 associate members, and 16 student members. During the year one ordinary member and six student members were elected, while six ordinary members and three associate members resigned. One corresponding and two associate members were transferred to ordinary membership, and one ordinary member transferred to associate membership.

We regret to report the loss, by death, of Dr. W. J. Hancock, who was the first Gold Medallist of the Society. The Council has supported the efforts of the University to erect a memorial.

COUNCIL.

Ten ordinary meetings of the Council were held during the year.

Mr. D. C. Swan resigned the position of Joint Honorary Secretary prior to leaving for a position on the staff of the Waite Research Institute, South Australia, and Mr. C. A. Gardner was appointed in his stead. Messrs. R. E. Gatherer and G. S. Compton were appointed auditors.

FINANCE.

The statement of receipts and expenditure for the year is the subject of a separate report. The grant received from the Treasury was at the rate of £80 per annum instead of £100, the reduction being effected in accordance with the Financial Emergency Act. The Council wishes to express its thanks to the Government for the subsidy. The publication of papers in the *Journal* has been somewhat curtailed, and authors have been required to contribute towards the cost of reproduction of plates and figures.

PUBLICATIONS.

Volume XVII. of the *Journal* was completed during September, while Volume XVIII. is well in hand.

C. A. GARDNER,

G. R. W. MEADLY,

Joint Hon. Secretaries.

ROYAL SOCIETY OF WESTERN AUSTRALIA.

Hon. Treasurer's Statement of Receipts and Expenditure for the year ending 30th June, 1932.

Receipts.

	£ s. d.	£ s. d.
Balance in Bank, 1st July, 1931—		
Medal Fund	22 7 3	
General Fund	8 3 6	
		30 10 9
Subscriptions		104 17 6
Authors' Reprints and Donations		15 13 0
Government Grants, July, 1931, to June, 1932		80 0 0
Excursion Receipts		7 7 6
Refund		1 4 9
Interest on Current Account		2 1 4
		£241 14 10

Expenditure.

	£ s. d.	£ s. d.
Petty Cash		9 6 2
Typing		4 7 6
Books and Stationery		6 5 7
Hire of Hall for Annual Meeting, July, 1932		3 3 0
Honorarium to Editor (Vol. XVII.)		15 15 0
Post Office Box Rent, 1st January, 1932, to 31st December, 1932		3 0 0
Museum Trustees' Fees, 1st July, 1931, to 30th June, 1932		16 16 0
Excursion Expenses		6 0 0
Government Printer—		
1. Printing 12 pages and cover of Vol. XVII.	19 18 9	
2. Printing Papers, 1-10, Vol. XVIII.	93 1 3	
3. Printing Programme Cards, July, 1931, to June, 1932	3 7 6	
4. Miscellaneous Printing	1 11 8	
		117 19 2
Balance in Bank, 30th June, 1932—		
Medal Fund	23 0 0	
General Fund	36 2 5	
		59 2 5
		£241 14 10

In addition to the above a sum of £132 6s. 0d. (Endowment Fund) is held on fixed deposit at 3½ per cent. interest for two years, maturing 12th June, 1934, at the Commonwealth Bank, Perth.

Examined and found correct—

R. E. GATHERER,
G. SPENCER COMPTON,
Hon. Auditors.

H. A. PITTMAN,
Hon. Treasurer.

6th July, 1932.

ABSTRACT OF PROCEEDINGS, 1931-1932.

14th July, 1931—

Paper—Physiography and Geology of the Upper Swan Area, Messrs. Fletcher and Hobson, communicated by Prof. E. de C. Clarke.

11th August, 1931—

Paper—" The West Australian Simuliidae." Mr. F. H. N. Drummond, communicated by Mr. D. C. Swan.

Lecture—" Agriculture in Russia." Mr. B. L. Southern.

8th September, 1931—

Paper—" The Problem of our Surplus Sheep." Mr. G. L. Sutton.

13th October, 1931—

Paper—The Genetic Improvement of Merino Sheep. Mr. C. B. Palmer.

Paper—West Australian Orthotetenae," Miss L. Hosking.

Lecture—" The Ticks of Australia," Mr. D. C. Swan.

10th November, 1931—Faraday Centenary.

Lecturette—" The Life and Work of Faraday," Mr. R. Davis.

Lecture—" One Hundred Years after Faraday," Mr. W. G. Hayman

8th March, 1932—

Lecture—" A Botanical Survey by Caravan," Mr. C. A. Gardner.

12th April, 1932—

Paper—" On Helvite from Mt. Francisco," Mr. H. Bowley.

Papers—" Contributions to the Mineralogy of West Australia," and " The Occurrence of Andalusite, Kyanite, Sillimanite and Staurolite in the Chittering Valley," Dr. E. S. Simpson.

Lecturette—" The Oleo-resins of two West Australian Woods—Acacia acuminata and Myoporum serratum," Mr. H. E. Hill.

10th May, 1932—

Paper—" Copper Bunticides," Mr. B. L. Southern, A.A.C.I., was tabled.

Paper—" An Ecological Analysis of the Plant Communities of the Jarrah Region, occurring on a small area near Darlington," Mr. R. F. Williams, B.Sc.

Lecture—" Gas in Warfare," Mr. G. E. M. Dean, A.A.C.I.

14th June, 1932—

Paper—" Mineralogy of certain West Australian Soils, Miss D. Carroll, B.A., B.Sc., was tabled by Professor Clarke.

Lecture—" Primitive Insects," Mr. H. Womersley, A.L.S., F.E.S.

Lecturette—" Cereal Smuts and their Control," Mr. H. A. Pittman, B.Sc.Agr.

Lecturette—Copper Bunticides, B. L. Southern, A.A.C.I.

BIOLOGICAL SECTION.

The first meeting of this section which was formed for the more intensive study and discussion of biological papers was held on 26th April, 1932, when the following office-bearers were elected :—

Chairman—Mr. H. Womersley.
Hon. Secretary—Mr. C. F. H. Jenkins.
Committee—Miss E. Bowley, Messrs C. A. Gardner, L. Glauert, L. Newman and R. F. Williams.

PROCEEDINGS.

26th April, 1932—

Paper—" West Australian Macropodidae," Mr. L. Glauert.

24th May, 1932—

Paper—" Aims and Scope of the Biological Section," Mr. H. Womersley.

28th June, 1932—

Paper—" The Endocrine Glands and their Effect on Evolution," Mr. G. Bourne.

The section has decided to make a complete biological survey of that portion of the coastal plain extending from Gingin to Mandurah, described by Mr. W. B. Alexander in his paper—" The Birds of the Swan River District."

JOURNAL OF THE ROYAL SOCIETY OF WESTERN AUSTRALIA,
VOL. XVIII., 1931-32.

THE KINO OF EUCALYPTUS CALOPHYLLA.

PRESIDENTAL ADDRESS

BY

L. W. PHILLIPS, M.Sc., A.A.C.I.

Delivered in July, 1932. *Published 26th May*, 1933.

INTRODUCTION.

Kinos are the reddish astringent exudations from trees and shrubs. They are usually soluble in water and always soluble in alcohol. They are distinguished from gums, which are usually light in colour, sweetish in taste and insoluble in alcohol, and from resins, which are also lighter in colour but soluble in alcohol and insoluble in water.

These kino exudations began to assume some economic importance during the eighteenth century owing to their introduction to medicine. Fothergill (62) 1757, appears to have been the first to describe the various medicinal uses to which the kino of *Pterocarpus marsupium* from Malabar might be put. He named the drug "Gummi rubrum astringens," from which the common name "red gum" is derived. Lewis mentions this drug in his materia medica of 1757, and in the 1784 edition of the same work he uses the name "*kino*" for the drug, giving "Gummi rubrum astringens" as a synonym. He regarded the kinos as substances intermediate between the true gums and the true resins and so classed them as "gum resins." He confirmed their medicinal uses as vegetable astringents, etc. Kino was later introduced into the British Pharmacopœa as official, and is now described as "the juice obtained from incisions in the bark of *Pterocarpus marsupium,* heated to boiling and evaporated to dryness."

The characteristic exudations of our Australian forest trees appear to have attracted the attention of the earliest English navigators to Australian shores, *e.g.*, Wm. Dampier (1), referring to the trees of that part of New Holland visited by him in 1685, states, *inter alia,* "the woods are not thick; most of the trees that we saw are Dragon trees, as we supposed, and these, too, are the largest of any there. . . . The gum distils from the knobs or cracks that are in the bodies of the trees. We compared it with some gum dragon or dragon's blood that was aboard and it was of the same colour and taste." White (2) in his Journal, written 1799, refers to some of the gums exuding from the trees as being "a very powerfully astringent gum resin of a red colour much resembling that known in the shops by the name of kino, and, for medicinal purposes, fully as efficacious." Naturally, Eucalyptus kino became incorporated into the unofficial materia medica of the early Australian pharmacists, and a large number of papers have been published in pharmacy journals concerning the suitability of the Australian kinos for the various preparations in which Malabar kino was directed to be used. The 1871 edition of Squire's "Companion to the B.P." included the material as an unofficial drug under the name of Gummi Rubrum. In

1871 Weisner reported that the tannic acid of the so-called red gum of Australia was kinotannic acid identical with that of the ordinary kinos and that these gums therefore should be ranked as true kinos. In spite of this semi-official recognition, however, very little trade in Australian kino was developed, as while it was known that there was considerable variation in properties medicinally, practical differentiation by shippers was found to be difficult; and, owing to their ignorance of which species of Eucalypts yielded suitable products, the Australian kino gained a very bad reputation on the London and German markets.

Maiden (3) in 1889 commenced a systematic study of the chemical and physical properties of the kinos with a view to utilising the results as an aid in the diagnosis of Eucalypts. He divided Eucalyptus kinos into three groups:—

1. *The Ruby Group*—completely soluble in water and alcohol, yielding ruby-coloured solutions. They consist entirely of tannins.
2. *The Gummy Group*—insoluble in alcohol. This thought to be due to a gum. Later shown by Smith to be due to 35 per cent. tannin glucoside. Remainder is free tannin.
3. *The Turbid Group*—soluble in alcohol and hot water, but their aqueous solutions become turbid on cooling. The turbidity was later shown to be due to two crystalline compounds—Eudesmin and Aromadendrin.

Both compounds were present in the kino of *E. hemiphloia,* whereas the kino of *E. calophylla* contained aromadendrin only, while that of *E. Punctata* contained eudesmin alone. The turbid group was therefore divided into three sub-groups:—

(a) Kinos containing aromadendrin and eudesmin.

(b) Kinos containing aromadendrin only.

(c) Kinos containing eudesmin only.

Maiden found that the kino of *Angophora melanoxylon,* like that of *E. calophylla,* contained aromadendrin only and drew attention to the resemblance between the leaf venation of these two species. Baker and Smith (4), Robinson and Smith (5), and Cambage (6) further investigated the relationship between the botanical characteristsics and the chemical constituents of many species, and their observations may be summarised by stating that the essential oils and kinos of the various species vary in composition in a manner determined apparently by the order of their evolution. The primitive eucalypts yield essential oils containing few oxygenated compounds and kinos containing the crystalline substances aromadendrin and, or eudesmin. The eucalypts of later evolution yield oils containing compounds of a greater degree of oxidation, while their kinos are composed principally of tannins free from crystalline compounds.

The accumulation of knowledge concerning the properties of the various species of kino led in 1914 to the inclusion of the "Kino Eucalypti" as an official drug of the British Pharmacopœa.

THE OCCURRENCE OF KINO OF E. CALOPHYLLA.

E. calophylla (red gum or marri) is a tree occurring in timber forests mixed with *E. marginata* (jarrah) and *E. diversicolor* (karri) in a belt of country in the extreme south-west of Western Australia. It is a large tree, obtaining a height of 100 feet or more with an average girth of 9 feet breast

high, but is of little value as timber owing to the presence of numerous kino veins. "Kino" appears in the form of "veins" or "pockets" which may be superficial or deep-seated, and is also formed in internal cavities which may or may not have communication with the exterior. Large quantities of kino may collect in these internal reservoirs, and as much as ten gallons of liquid has been obtained from a single reservoir.

In 1921 the present Conservator of Forests, Mr. S. L. Kessell (7), then Forestry Working Plans Officer, studied the formation of kino veins in the growing trees. He concluded that the kino veins and pockets were definitely pathological phenomena developing as the direct result of injury to the tree.

The injury giving rise to a kino vein must be such as to cause a break in the bark of the tree and allow access of air to the recently formed sapwood. It would seem that the undifferentiated xylem region of the actively dividing cambium must be exposed to the air. The most fruitful causes of injury leading to the formation of kino veins are wood boring larvae of the genus *Phorocantha,* which, as grubs of small size, bore their way through the bark to the sapwood. The entrance hole is subsequently occluded but, on examination, is found to be the nucleus of a kino vein. The small larvae bore within the bark. Where they touch the sapwood the nucleus of a kino vein is formed. The borer appears to channel its way up the tree in an irregular spiral. The entrance hole is soon occluded and apparently, from time to time, the larva bores its way out to the air, then turns round and continues its upward course. In due course it prepares a pupal chamber by first cutting away the sapwood and part of the bark, so as to leave a free exit for the imago and then bores into the wood again. The subsequent occlusion of these surface borings give rise to a small kino pocket. Kino veins are also formed as the result of the turning back of branches, mechanical injury caused by falling timber, etc.

It is noted that certain peculiarities of cell structure are intimately associated with the occurrences of kino veins. From the nucleus of the vein the development takes place in all directions on a cylindrical surface. Its radial development is invariably limited to a fraction of an inch, usually about one-tenth; while the longitudinal and peripheral development may extend several feet. Kino pockets are only formed when space may be left under the occluding tissue which subsequently becomes filled with kino, consequently the presence of pockets containing liquid, even when deeply seated, may usually be located by external swellings.

Subsequently, the Department of Forests, Western Australia, conducted further investigations on the production of kino veins in the tree in order to ascertain whether the production could be artificially stimulated with a view to the production of regular crops of kino. The normal sources of tanning materials are tree barks, and their collection involves the death of the tree. If kino production could be stimulated at will, and tapping arranged at regular invervals, the supplies could be regarded as inexhaustible. The results of this interesting project have been reviewed in several of the annual reports of the Department of Forests. Efforts to obtain a heavy and sustained flow of kino by systematic tapping by means of holes with augers have not yielded encouraging results. It has, however, been found that if, instead of endeavouring to stimulate the production of natural reservoirs, the bark of the tree be injured by a series of axe cuts applied systematically in vertical overlapping rows, each axe cut being about two feet from the last, long peripheral kino vein formations are produced and

weak points in the bark remain for the escape of the kino. The following year a bark impregnated with "crystalline," or oxidised kino, containing about 45 per cent. of kino or 30 per cent. tannin can be collected (8). The kino is admixed with the bark and is not contained inside the fibres. Hence, when the kino bark mixture is treated, the extract can be drained off the barks and the usual battery system of leaching can be considerably simplified. The bark itself is very low in tannins (1 — 4 per cent.), and this is somewhat remarkable. The investigator in charge of these tanning investigations, Mr. W. E. Campion, pursued these studies also from the physiological standpoint, and presumably his general conclusions on the physiology of kino formation will be published at some future date.

KINO AS A TANNING AGENT.

Marri kino has long been recognised as a tanning agent, particularly for bush tanning work. The aborigines are reputed to have used it also. Tanners have not used it to any great extent, as it is decidedly insoluble in cold water, and its reddish colour gives a dark red leather, not unlike leather tanned with mangrove bark. A straight tanning gives also a brittle crackly leather, though the weight obtained is good. The tans are slow of diffusion, and leather tanned with a large proportion of kino exhibits a light streak even after many weeks in the pits. In such cases the outer portions of the hide are more heavily tanned than the inner portions. On the other hand, it gives good weight and such a tannage appears to carry grease very well (9).

During the war, the increased interest in local raw materials led to work being done in the Government Chemical Laboratories of this State on the tannin content of kino and the treatment necessary to render it suitable for use as a tanning agent. This, in turn, led to the then Institute of Science and Industry conducting more extensive investigations on this question (9). Coghill (10) claims that treatment of marri kino with normal sodium sulphite and the acid sulphite in the proportion of 1 to 8, gives a tannin extract of reasonably good quality in respect of solubility, tannin content and colour. It is considered that the product thus obtained compares quite favourably with ordinary querbracho tannin extract of South American origin, which constitutes the greater proportion of the annual imports of tanning extracts to Australia, amounting to practically £50,000 per annum. Querbracho extract is used for tanning heavy leather, a purpose for which the treated marri kino should be well suited, and there appears to be no reason why marri kino extract should not provide a satisfactory substitute for querbracho in Australian tanneries.

Mr. W. E. Cohen (11), formerly in charge of the investigations carried out by the Council for Scientific and Industrial Research at the tannin extract plant at Crawley, has this year published details of a process whereby satisfactory tannin extract can be made. His method avoids all attempts to solubilise the more complex phlobaphenes which are only sparingly soluble by making the extraction of the kino impregnated bark at 60°C. and subsequently treating the infusions with sodium bisulphite at 100°C. and evaporating. By this means a satisfactory liquid tannin extract has been obtained. The product was sold to various tanneries which have reported that the extract produced good leather which was readily saleable. The utilisation of this source of tannin is now a matter for private industry to take up, and it is pleasing to note that one Western Australian manufacturing firm is proposing to enter this industry with a view to the production annually of £20,000 worth of tannin extract.

THE CHEMISTRY OF THE KINO.

In spite of the fact that so much work has been done on kino, our information concerning its fundamental chemistry is extremely meagre. This is because most of the chemical analyses have been made from a technical point of view only and the methods followed have been the standard methods of the Leather Chemists' Association. These, while providing excellent bases for comparison of the material as a tanning agent with other well established tanning materials, afford little information concerning the chemical nature either of the tannin or other substances associated with it in the kino. Hence the reports of these investigations do not provide sufficient data on which a definite theory for the bio-chemistry of kino production can be based.

Lanterer (12), in 1895, stated that certain kinos on standing gave precipitates of ellagic acid, and consequently were pyro-gallol derivatives. Maiden and Smith (13) showed that the substances separating from aqueous extracts of the kino of *E. hemiphloia* and producing turbidity in the extracts, were crystalline compounds which they named eudesmin and aromadendrin. Neither substance contained pyrogallol, but each contained a catechol nucleus. Eudesmin was assigned the formula $C_{26}H_{30}O_6$. The kino of *E. calophylla* was later found by Smith (14) to contain aromadendrin free from eudesmin. This paper was in the nature of a reply to the claim of Lanterer that the turbidity of kinos was due to ellagic acid. He noted that with nitric acid a blood red colouration was obtained and as, until that time, this reaction had been considered to be specific for ellagic acid, the conclusion of Lanterer concerning the type of tanning was considered to be thereby explained. As a matter of fact, recent tests devised by Ware to discriminate between the tannins in the presence of other phenolic bodies show the presence of pyrogallol tannin in the kinos from *E. gunnii* and *E. phellandra* in addition to a catechol tannin, while those from *E. microcorys* and *E. maculata* contain both gallotannin and ellagitannin in very appreciable quantities. Lanterer's observations, therefore, were probably not so inaccurate as were formerly considered to be the case. In addition to aromadendrin, the kino of *E. calophylla* contains little besides tannin and the corresponding phlobaphenes. A purple coloured pigment and some gallic acid are usually present.

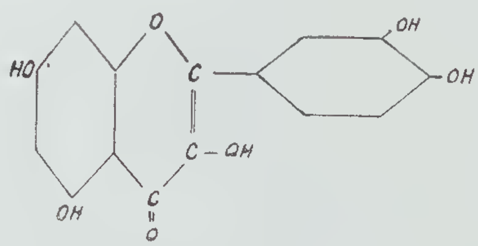
(a) THE NATURE OF AROMADENDRIN.

Aromadendrin is sparingly soluble in water, dissolving in alkalies to give yellow-coloured solutions varying from light yellow with lime water to a characteristic orange colour given by ammonia. With concentrated sulphuric acid it dissolves to give a yellow solution. On warming, the solution becomes orange. Reducing reactions are given with Fehling's solution, silver and gold salts. With ferric salts it gave a purplish brown precipitate or colouration. The formula assigned by Smith was $C_{29}H_{26}O_{12}$. He was struck by certain similarities with catechin, a crystalline substance separating from the extracts of catechu or cutch, and which is an important tanning any dyeing material. While not actually a tannin itself, it is absorbed by the hide and there is gradually converted to catechu tannin acid. Aromadendrin similarly does not precipitate gelatin and is therefore not a tannin, but its occurrence with the tannin in the kino was regarded by Smith as very significant. Its solubility in water and solvents, its reducing properties and its reaction with lead acetate, are very similar. Moreover, on fusion

with caustic potash, the compounds phloroglucinol and protocatechuic acid were indicated and these have long been recognised as the fusion products of catechin. The principal differences from catechin are its reaction with sulphuric acid, the absence of dyeing properties and its behaviour on heating with glycerine to 200°. Whereas catechin under this treatment decomposes to give catechol, aromadendrin decomposes to give a yellow resinous looking substance almost insoluble in cold water, but readily dissolving in alcohol to form a yellow solution possessing strong tincorial properties and dyeing skin, wool, etc., bright yellow. He called this substance "kino yellow."

The chemical formula of aromadendrin has been the subject of considerable speculation. Smith's formula is not considered to accurately represent its composition because of the difficulty in obtaining the substance free from water of crystallisation without leading to a dehydration product. It is therefore necessary to consider the relation of aromadendrin to compounds the structures of which are well established.

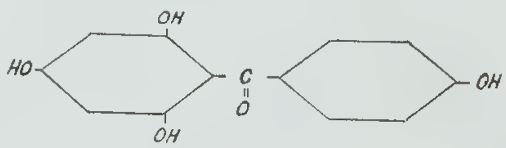
With an aluminium mordant, aromadendrin dyes wool lemon yellow (15), and from this Perkin suggested a possible relationship to cyano maclurin $C_{15}H_{12}O_6$.



This gives similar fusion products to those given by Smith for aromadendrin and is associated with tanning material in old fustic.

Thorpe (16) gives the constitution as maclurin monomethyl ether. This is probably to account for the fact that it is difficult to obtain confirmation of protocatechuic acid as a fusion product. This however is not a solution to the problem, as no methoxyl can be detected.

Nishikawa and Robinson (17) gave $C_{13}H_{10}O_5$ or $C_{15}H_{14}O_7$ as possible formulæ. They believed the former to be correct and, if so, to explain its chemical behaviour it would be a 2. 4. 6. 4′. tetrahydroxy benzophenone



since the meta compound would yield trinitro-m-hydroxybenzoic acid on destructive nitration and the ortho compound should lose water to form 1 : 3 dehydroxy xanthone, and such transformations could not be realised. The three possible isomers were prepared by them and, while similar in certain respects to aromadendrin, were definitely different substances. It was therefore concluded that the formula $C_{15}H_{14}O_7$ was more correct, but no evidence for this was cited, it being stated that the work on the constitution of aromadendrin was in progress and would be published.

It is my opinion that aromadendrin is a hydrate existing in different degrees of hydration according to the conditions of crystallisation, etc. Chemi-

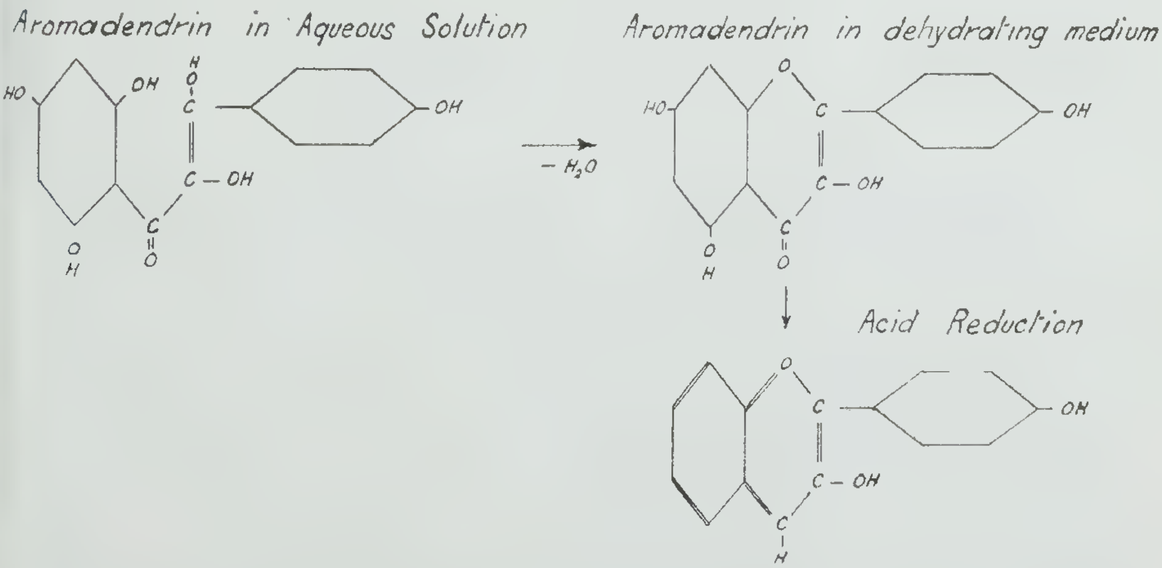
cal reactions that take place under dehydrating conditions follow a different course to those occurring when water is present. A detailed report of these differences will be communicated on a more suitable occasion.

Combustions of pure specimens dried at 100° gave figures corresponding to the formula $C_{15}H_{12}O_6$ or $(C_{15}H_{12}O_6)_2 3H_2O$ crystallised from water. As the precipitate obtained with lead acetate gave 45 per cent. PbO (*vide* Smith) and $Pb(C_{15}H_{10}O_6)$ corresponds to 45.1 per cent. PbO, this formula $C_{15}H_{12}O_6$ can therefore be regarded as representing the composition under anhydrous conditions.

Other analytical data are very difficult to obtain. For example, acetylation is accompanied by the production of a phloroglucide and the acetylation number obtained refers to the new compound and not to aromandendrin. Confirmation of the formula must therefore be sought indirectly from a study of the decomposition products and the chemical relationships of aromadendrin to other substances, the chemical natures of which are well understood.

Smith found that the fusion products of aromandendrin were phloroglucinol and protocatechuic acid, but the latter compound is not obtained if the material used has been entirely freed from the associated tannin.

Although aromandendrin is colourless, the general behaviour of the alkaline solutions is suggestive of the yellow plant pigments the flavones; but whereas the flavones on reduction yield a red pigment in acid media, changing to purple in neutral solution and blue in alkaline media, aromandendrin gives a red pigment on reduction which is converted into a colourless compound by alkalies. If, however, the reduction is carried out at 100°C. a purple pigment is obtained from the red pigment. The blue pigments can be obtained by taking steps to see that the medium is anhydrous, *i.e.*, by dissolving in glacial acetic, adding concentrated sulphuric acid, diluting with absolute alcohol and adding hydrogen chloride gas before reduction. The red colour is much fainter and more closely allied to the normal way in which the flavone is reduced to the authocyanidin. These results are interpreted as indicating that the yellow solution given with sulphuric acid is a true flavone and can be reduced to a true authocyanidin, but that the normal aromandendrin is reduced to an allocyanidin, *i.e.*, an open chained compound.



i.e., these reactions can be interpreted by regarding the two benzene nuclei in the compound under ordinary conditions connected by a propane chain and that under conditions favouring dehydration or at higher temperatures

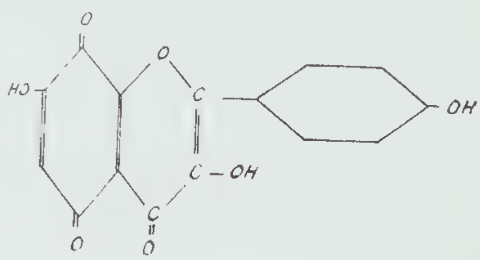
there is loss of water forming a pyrone ring. This, possessing a true flavone structure, reduces to an anthocyanidin giving the complete reactions with alkalies, whereas the open chained compound can form phenolic salts or purple pigments only.

Ware (18) assumes that the yellow compound formed by heating in glycerine, *i.e.,* kino yellow is identical with the yellow substance obtained with concentrated sulphuric acid. While his assumption that the latter is an oxonium compound is probably correct, kino yellow cannot be reduced to a red pigment and as far as can be seen has a structure much more complex than is necessary to assign to aromadendrin.

Aromadendrin undergoes an interesting oxidation reaction with hydrogen peroxide. While this alone has no effect, in the presence of potassium carbonate or phosphate, it produces a purple colouration with aromadendrin quickly in the first case, and more slowly in the second. Since a thermostable peroxidase enzyme can be demonstrated to be present in the cambium of the marri tree, this is regarded as evidence that the action of kino production is first that of oxidation.

Miss Wheldale (later Mrs. Onslow), in working on the theory of the production of the anthocyan pigments from the corresponding flavones, at one time considered that the action was one of oxidation and, in company with Neirenstein, prepared red oxidation compounds erroneously regarded by them as anthocyanidins. Their results however show that coloured oxidation compounds can be obtained from the flavone compounds.

The red oxidation products of Wheldale and Neirenstein have been assigned formulæ of the type—

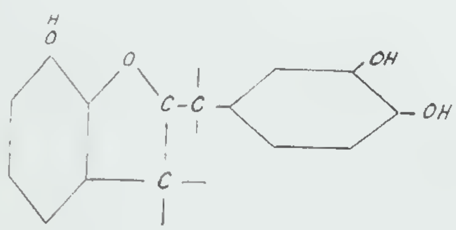


(b) THE TANNIN OF THE KINO.

Fundamental work on the tannin of kino has been carried out by A. McGookin and I. M. Heilbron. They worked on a sample of kino forwarded from the Forest Products Laboratory, Perth, 1925. Aromadendrin was removed by the method of Smith but was recovered in too small a quantity to permit of further work on this compound. The remainder of the kino was regarded by them as consisting of a single tannin and they refer to this tannin as kino itself. They claim that precipitation from the solutions in the ordinary tannin solvents such as alcohol, acetone, theyl acetate, etc., by means of liquids in which the tannin is insoluble, *e.g.,* ether, choloroform, petroleum ether, etc., yielded products which were chemically indistinguishable. Fractional precipitation of the aqueous solutions of the tannin with neutral aqueous solutions of lead acetate, resulted in the production of identical substances in each case. Further, excess of the lead reagent gave a filtrate

which was free from organic material, so that apart from aromadendrin the kino contained no substance other than the single tannin. Methyl and acetyl derivatives of the tannin were prepared and these gave analytical figures indicating the empirical formula of the original tannin of the kino to be $C_{15}H_{11}O_4(OH)_3$. The presence of a catechol nucleus within the molecule was shown by the oxidation of the methyl compound to veratric acid and the production of catechol and protocatechuic acid on fusion with potash. Distillation in vacuo yielded catechol and a minute quantity of guaiacol. The methyl compound on distillation yielded products which gave evidence of including veratrol and guaiacol. The presence of guaiacol among the decomposition products was not regarded as evidence of the presence of a free hydroxyl in the molecule, as exhaustive methylation experiments failed to introduce a fourth methyl group into the methyl compound, and moreover prolonged acetylation invariably resulted in the separation of a triacetyl derivative. They therefore considered that this hydroxyl group is formed from a ring structure.

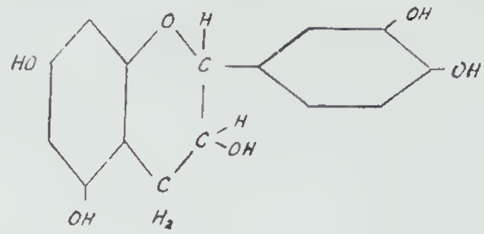
From these results it was inferred that kino tannins must contain both the catechol and protocatechuic acid nuclei. The catechol nucleus forms part of the ring, and the three hydroxl groups are replaced by methoxyl groups in the methylated compound. The two nuclei above account for thirteen carbon atoms and the remaining two carbon atoms were regarded by McGookin and Heilbron as constituting part of an easily ruptured heterocyclic ring as follows:—



The production of oxalic acid as part of the products of oxidation was regarded as supporting this view.

The fact that 5 hydrogen and 3 oxygen atoms of the molecular formula are not accounted for and the difficulty of distributing these throughout such a formula was fully appreciated and regarded as evidence that the molecule must be more complex than the simple skeleton given. A molecule of such a skeleton structure on decomposition with potash would be expected to yield catechol and protocatechuic acid, as well as oxalic acid on decomposition with KOH, but these products can be as equally well explained by other structural formulæ. This suggested structure conformed to the type of structure that had a little earlier been assigned by Freudenberg (20) to the catechin tannins, i.e., derivatives of $\alpha-\gamma-$ diphenylpropane. However, Freudenberg (21) and his co-workers the same year succeeded in effecting a synthesis of epicatechin by the reduction of cyanidin. Robinson in the same

year effected this synthesis independently. This reaction definitely fixes the constitution of this tannin and also of catechin itself as—



The conclusions of McGooken and Heilbron must be accepted with reserve. Firstly, their contention that the kino consists of a single tannin is not in accord with the experience of Australian workers, and secondly, the skeleton structure assigned to this single tannin must be reviewed in the light of our present knowledge of the structure of catechin. It is to be regretted that their work was done on a single sample forwarded from Perth, as ordinary specimens of kino vary considerably in their physical, chemical and tanning properties. As previously stated, there are thin watery liquid kinos obtained from deep-seated pockets, the more viscous kino obtained from the kino veins, as well as the solid kinos encrusting the barks. In general the ash in relation to total dry solids is much higher in the first case than in the last, indicating that in such cases the kino is probably diluted with sap. In the other cases, oxidation occurs causing the kino to solidify when exposed to the atmosphere. When thin liquid kinos are tapped from the tree and allowed to stand, the liquor gradually becomes viscous, finally solidifying into a real vitreous solid mass. Oxidase enzymes can be shown to be present in the final product. This variation in composition has been the subject of comment by Maiden, Mann, Salt, and Coghill.

Marri kinos usually contain in addition to the kino tannin and aromadendrin, insoluble tannins, *i.e.*, tannn reds or phlobaphenes, whch it has been the aim of various technical investigations to convert into soluble tannins. In addition to these there is the characteristic colouring matter—the presence of which McGooken and Heilbron found so troublesome when purifying their various derivatives. Moreover, after the catechol tannins have been precipitated by Ware's method the presence of gallic acid is indicated. These substances must all be taken into account if a picture of kino formation is to be evolved. The probability of a second tannin present is also indicated, not only by the presence of gallic acid, but by the occurrence of guaiacol in the vacuum distillation products of the kino and by the presence of a small amount of methoxyl corresponding to a little more than 1 per cent. of the total kino—an amount indicating a second substance present admixed with the single specific tannin of McGooken and Heilbron. It is, however, my opinion, that all these substances are genetically related, having a common skeletal structure and differ from one another chiefly in the degree of oxidation of the different carbon atoms.

(c) BIOCHEMICAL EVOLUTION OF THE KINO.

The establishment by synthesis of the structure of catechin is of extreme importance in connection with the present problem, as it has placed the chemistry of catechol tannins on an entirely different basis. These may now all be regarded as originating by polymerisation and condensation of the

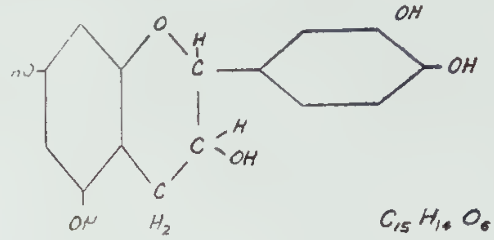
crystalline catechins. Freudenberg postulates that for every catechol tannin we will ultimately find a corresponding catchin, *i.e.,* tannin production in the plant probably follows a scheme such as the following:—

$$
\begin{array}{c}
\text{Flavone}\\
\text{H}\downarrow\ \uparrow\text{O}\\
\text{Anthocyanidin}\\
\downarrow\text{H}\\
[\text{Catechin}]\ \text{not always observed}\\
\downarrow\\
\text{Tannin}\\
\downarrow -\text{H}_2\text{O}\\
\text{Phlobaphene}
\end{array}
$$

This view of tannin formation is most suggestive. As shown by Kessell, the primary cause of kino vein formation is the access of air to the cambial layer. He regards this as indicating bacterial infection and considers that the general morphology of vein formation is in accord with that view. The experiments of Campion have not supported this contention, although it has to be conceded that inoculation by auger holes does not reproduce the conditions set up by the insect borer. It is not however necessary to postulate infection by bacteria. In the pyrenchymatous tissue adjacent to the cambium we have a normal flavone-anthocyanin system concerned with the vital life processes of the plant. The access of air to the enzymatic systems at once sets up oxidation leading to loss by pigmentation of the flavone forming aromadendrin and its oxidation product, the purple pigment. The plant is concerned with shutting off the affected area, and tannins are produced by the reductase enxymes (*i.e.,* by the hydrogen of water) reducing the anthocyanidin to catechin and, in turn, by condensation and polymerisation to tannins—the oxygen from water converting the phenolic group of aromadendrin to a catecol grouping. That this view is not unlikely is supported by the well-known fact that tannin reduces enzymatic activity in the tissues containing it and that the tree, to reduce the extent of the injury, attempts to shut off the affected part from the plant circulatory system. It must be remembered that normally neither the Angophora nor *E. calophylla* produce tannin either in the heartwood or in the bark. These trees represent the more elementary types of eucalypts, and the necessity for producing tannin in this way has probably led to the eucalypts of later evolution producing tannin in the bark so that a more effective defence against insect injury and consequent disturbed metabolism may be provided.

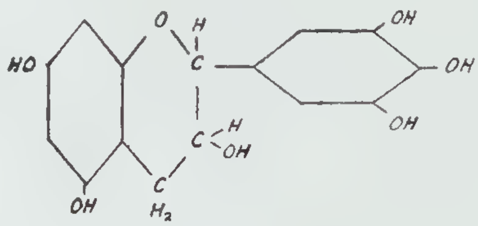
It is considered therefore that the skeleton structure of aromadendrin will also be the structure of the catechins and the resulting tannins, *i.e.,* the

parent substance of kinotannin must have a structure similar to that of aromadendrin, and if the structure assigned to aromadendrin is correct, then the kino catechin must have the structure—



$C_{15}H_{14}O_6$

This postulates a phloroglucinol grouping in the tannin, evidence for which was not obtained by McGooken and Heilbron. This probably means that condensation has been effected by ether formation involving loss of the phloroglucinol hydroxyls. This would meet the remainder of their experimental requirements without the difficulties involved in their formula. Their analytical figures gave a formula $C_{15}H_{14}O_7$. This is a more highly oxygenated substance than anhydrous aromadendrin appears to be. This suggests that the chemical reactions are complicated by further oxidations leading to a pyrogallol group in the molecule. In this regard the presence of gallic acid in the kino is most significant and suggests the presence of a second tannin of the structure—



In general, then, the view of Freudenberg enables us to obtain a picture of kino production in which all the substances present are related one to the other and architecturally similar—their differences one from the other being the degree of oxidation of the various carbon atoms.

Further work has to be done in definitely identifying the cyanidin which is obtained by reduction, and also whether the tannins are closed ring compounds or open as in normal aromadendrin.

I will conclude by quoting from an address of Freudenberg's at the B.A.A.S. meeting in Cape Town in 1929:—

We may distinguish two kinds of biochemical research. In the first kind, for example, that of indigo, or other chemical individual, the goal lies in front of the investigator like the summit of a mountain. He can measure it and at last venture to attack the summit by undertaking a synthesis. In the other kind the chemist explores the large tracts of amorphous substances where marsh land prevents access and primeval forest obscures the view so that no fixed points are available on which to base a survey. The unknown field must be penetrated and a view obtained by cutting down some giants of the forest and also by building up artificial structures from which to survey the surrounding country.

To-night I have endeavoured in this survey of kino formation to point out some of the paths across the marsh land; to cut away some of the forest growth and, I hope, thereby enabled a clearer picture to be obtained of the territory waiting to be surveyed by future workers in this field.

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1.—WEST AUSTRALIAN SIMULIIDAE.

By F. H. N. Drummond, B.Sc.

Read 11th August, 1931: Published 20th November, 1931.

The Simuliidae, which have a world-wide distribution, have been intensively studied in Europe and America on account of their attacks on man and his domestic animals. The Australian representatives with a few exceptions are not characterised by blood sucking habits and hence they have not attracted much attention in the past. In 1925 A. L. Tonnoir (1925) published an account of the Australasian Simuliidae, in which he dealt with twenty-one species of which fifteen were new. In this paper he also reviewed the previous records of species from Australia.

The Simuliidae is a well defined family of Nematocerous Diptera, distinguished from the rest of the super-family Bibionoidea* by the stout body and the broad wings devoid of cross-veins, and without a closed cell. The bases of the main veins are close together and almost parallel. The condition of the vein *Cu* is interesting. Dr. Tillyard (1925) states that the concave bend in the distal part of this vein is a very primitive character, found only in the wing of *Rhyphus*. The occurrence of a similar condition in the wings of Simuliidae must have escaped his attention, as his figures clearly illustrate this point.

The larvae which are sedentary are found together with the pupae, attached to stones and other stationary objects in fresh water streams.

No work has been done previously on the group in Western Australia although the adults were known to be troublesome at certain seasons of the year. It is now known that there are five species represented in the Darling Range area. Two of these I have been unable to identify owing to insufficient material. No female specimens of either of these species were obtained, and as a number of Australian species have been described only from the female, it was thought not to be advisable to describe the male and early stages which however are new.

The other three species, *Simulium ornatipes* Skuse, *S. tonnoiri*, n.sp., and *Austrosimulium bancrofti* Taylor, are very abundant and usually in association with one another although *A. bancrofti* was absent from some localities, *e.g.*, Lesmurdie.

* Mr. A. L. Tonnoir is now of opinion that the family Simuliidae should be placed in the superfamily Culicoidea.

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The adult flies with the exception of the female of *A. bancrofti,* were very rare in the field, although pupae were abundant in the streams. From observations extending from March to November I conclude that the flies breed all the year round where there is running water, even though the stream be reduced to little more than a trickle.

This statement does not apply to one of the undetermined species, which apparently has a very brief breeding period in the winter months. Larvae were quite abundant at Upper Swan in July, but had totally disappeared by September. Curiously enough, only males were obtained from larvae of this species bred in the aquarium.

Pupae and larvae are naturally more plentiful in the spring and early summer, as at this period there is a good supply of water and at the same time the warm weather speeds up the life cycle. With the exception noted above, the adults were never plentiful. In no part of the world are the males very abundant under natural conditions, but usually the females are plentiful in the vicinity of the streams in which they breed.

Simulium tonnoiri, n.sp., seems to have the widest distribution as the early stages are found in all classes of streams. *A. bancrofti,* on the other hand, seems to be more or less restricted to fairly large fast-flowing streams, and it is therefore strange that it does not breed in the Lesmurdie Falls region, as this is certainly one of the major streams in the area under discussion. The early stages of *Simulium ornatipes* are more abundant in slow flowing brooks and are comparatively rare at waterfalls.

Two larvae of an undetermined species of *Austrosimulium* were collected from a small stream in the Cannington Swamps area. This was rather an unusual situation as the water was very discoloured and the stream must have been a very temporary affair. Possibly they had been carried down after heavy rain from some locality in the hills.

Breeding.

Where possible, the flies were bred in the laboratory from the larvae, as this is the only satisfactory way of definitely connecting the three stages in the life cycle.

In the past, workers on the group were unable to breed the flies from larvae because the latter will not survive under ordinary aquarium conditions, as the aeration is insufficient, and further, as the larvae are sedentary and have no means of creating a current to draw in food, it is obvious that they would speedily starve in standing water. In recent years Tonnoir (1923) and Puri (1925) have successfully reared the adults from eggs under aquarium conditions.

Adults will emerge quite well from pupae if they are kept in a humid atmosphere, *e.g.* on damp cotton wool. Under these conditions larvae will live for a period varying from one to two days, and this is the most satisfactory method of dealing with them at the time of collecting.

The larvae were bred in a cascade aquarium of the style described by Tonnoir (1923) with a few modifications to suit the local conditions. Tonnoir states that in New Zealand the ordinary tap water contains sufficient food for the larvae. This does not apply here, as the water supply is subjected to various purification processes designed to eliminate living organisms. To provide food for the larvae, the water, before entering the cascade was passed through an aquarium where it picked up a certain amount of food material.

Another difficulty was provided by the variation in water pressure. This was overcome to some extent by means of a supply tank fitted with an outlet and an emergency escape tube. The water passed from the tank to the aquarium and was siphoned from the latter to the top of the cascade. The whole apparatus was capable of self adjustment in the event of a fall in water pressure. Such a decrease would lower the water level in each of the containers, and the flow in the cascade would consequently adjust itself. A rise in pressure would not affect the rate of working, as the excess water would escape by the emergency pipe.

In the case of the first batch of larvae the great quantity of rust in the water proved absolutely fatal, all the larvae dying within twenty-four hours. The rust was therefore filtered out as far as possible, but it was found to be impossible to remove it completely without seriously interfering with the running of the aquarium. Chemical methods of removal by precipitation were not attempted as it would be almost impossible to prevent contaminating the water. The rust which was not removed tended to choke the gauze attached to each bowl, and it certainly interfered with the health of the larvae. In many cases when dissections were made it was found that particles of rust constituted the major portion of the contents of the gut.

The construction of the cascade portion of the apparatus was exactly as described by Tonnoir. The object is to obtain a constant stream of water continually and entirely renewing the water contained in a series of small bowls placed one below the other on an inclined plane. This system is very convenient for observation, and when the larvae pupate the cocoons can be removed without difficulty.

In the other type of aerated aquarium which is recommended by Puri (1925), aeration is secured by bubbling air through it. An aquarium of this type was set up, the air current being obtained by means of a filter pump.

This experiment was not a success, possibly in part due to overstocking with larvae, and also to the fact that the aquarium was stocked with *Chara*. This weed is said to prevent the growth of mosquito larvae, and it may have a similar effect upon those of Simuliids. The difficulty of an aquarium of this type is to break up the bubbles of air. If this could be done, aeration would be more complete and the feeding would be more satisfactory.

No further work was done with this type of aquarium, as the cascade type is more convenient. Also, the current of air generated by the filter pump is determined by the water pressure, which, as stated above, is subject to a good deal of variation. A fall in pressure might result in the cessation of aeration, and consequent suffocation of the larvae.

It was found to be more satisfactory to keep the pupae on damp cotton wool in boiling tubes, rather than to allow the adults to emerge in the aquarium. On emergence the flies were allowed to remain in a clean dry tube for some hours before they were killed.

HABITS.

It is fortunate that Australian Simuliidae, with a few exceptions, are not blood-sucking forms, as in many ways the conditions are ideal for their breeding operations. Lea (1917) has reported some severe attacks on cattle in South Australia, but apart from these cases, they are not known to be responsible for much damage, but of course the habits of the majority of the species in Australia are very imperfectly known.

In New Zealand and Tasmania, however, blood-sucking forms are widely distributed, but even in these countries the damage is not extensive, whereas in some parts of Europe and America there are frequent reports of Simuliidae causing the deaths of cattle, horses and pigs. The saliva which the flies inject into the wound appears to have very toxic properties.

Only three Australian species have been definitely recorded biting man. The first record was that of *Austrosimulium bancrofti* from Queensland, and since then *Simulium terebrans* and *S. fergusoni* have been added from New South Wales and Victoria. *A. bancrofti* occurs quite abundantly in the Darling Range area of this State, and it is the only biting species so far recorded here. They are particularly vicious during the spring and early summer, and bite from morning to night, not only along the banks of the streams, but they also enter dwellings some distance from their breeding places.

Female flies of this species, taken in the field, bite freely in captivity when applied to the skin, but those bred out in the laboratory never exhibited this habit. After the bite, the irritation does not commence for a considerable time, twelve hours or more usually. Some persons are much more susceptible than others, the bites in their cases producing large swellings which later become almost black. These are intensely irritating and persist for nearly a fortnight, during which time a pus-filled head forms in the centre of each.

In accordance with their blood-sucking habits, Simuliidae at various times have been reported as carriers of disease. The first charge of this sort was made by Dr. Louis Sambon, who suspected that they were the vectors of pellagra, a fatal human disease in many parts of the world. This has since been shown to be due to an improper diet.

In South Africa, *Simulium damnosum* Theo., has been proved to be the carrier of *Onchocerca volvulus,* a nematode worm. The South American workers suspect Simuliidae of performing the same service for a closely allied parasite, *O. caecutiens.*

The work of Dry (1921) in Kenya indicates that *Simulium neavei* Roubaud, is the transmitter of a disease of natives characterised by a peculiar wrinkling of the skin and various internal disorders.

PREDATORS.

As might be expected from their sedentary habit, the early stages of Simuliidae are preyed upon by other aquatic animals. In the case of *S. tonnoiri,* n.sp., the cocoons are built in clumps and often Chironomid larvae were present about the bases of these, and in the material which collected there. In one case a Chironomid bred out from a tube containing these cocoons, and hence its pupa must have been present. If both the larvae and pupae are present in this situation it seems probable that the Chironomid larvae feed on the Simuliids.* In Eastern Australia and America, dragon-fly larvae have been observed feeding on Simuliid larvae, and on one occasion I observed a similar habit under aquarium conditions. The dragon-fly larva, which was placed in a bowl of the cascade aquarium, devoured eight larvae in the course of ten minutes. The fact that this larva had been starved for over a week no doubt made the Simuliids more acceptable than they would be under natural conditions. The possibility of using dragon-fly larvae to control the Simuliid pest in New Zealand is being investigated by Mr. A. L. Tonnoir.

* Mr. A. L. Tonnoir has pointed out that it is quite possible that the Chironomid larvae are merely commensals.

SYSTEMATICS.

Until recently the Simuliidae throughout the world were grouped into a single genus Simulium. In 1921, Dr. G. Enderlein (1921) brought forward a classification subdividing the genus into a number of genera. His classification was unsatisfactory, and has not met with wide acceptance.

A. L. Tonnoir (1925), working on Australasian forms, divided them into two genera. Those with antennae composed of eleven segments he left in the genus *Simulium,* and those with antennae composed of ten segments he placed in a new genus, *Austrosimulium.* This classification is satisfactory except in the case of *A. bancrofti,* the position of which will be discussed later. Tonnoir found that many of the species of *Austrosimulium* were almost indistinguishable in the adult stage, but that the early stages showed good systematic characters.

The most satisfactory characters of the adults for systematic purposes are the relative lengths of the joints of the antennae, and of the maxillary palps, the degree of curvature of the vein *Cu,* the tarsal joints of the hind leg and, in some cases, the genitalia. The Western Australian forms are easily separable on these characters, and also on their colouration which, however, is somewhat variable.

The larvae offer excellent systematic characters in the structure of the antennae, the arrangement of the teeth of the submentum, and in mature forms the shape of the gill spot. The anal armature is also distinctive but rather variable, and the same remark applies to the markings of the head capsule.

All the previously described Australasian larvae had antennae consisting of only two segments and an apical cone. It is curious that the antennae of all the Western Australian forms should have three segments* in addition to the cone. The division between the two basal segments is not so distinct as that between the second and third joints, but there are undoubtedly three segments present.

The pupal breathing organs are quite distinctive. Previously *S. aurantiacum* Tonn., was the only Australian species with branched pupal gills, but *S. tonnoiri,* n.sp., also shows this condition. The species of the genus Simulium so far described from Australasia are characterised in the pupal stage by the absence of a prominent basal horn, to which, in the case of *Austrosimulium,* the filaments of the gills are attached. The cocoon shows wide differences in shape and texture in the various species. The wall may be almost membranous and transparent, or it may be quite rough and, in some cases, foreign matter is incorporated in it. The cocoon may be attached by its ventral surface or by the posterior end only. Of the three species dealt with, two belong to the genus *Simulium,* and the third to *Austrosimulium.* As Taylor (1927) has pointed out, the position of *A. bancrofti* is doubtful. The genus *Austrosimulium* was erected by Tonnoir, the generic character being the condition of the antennae which were composed of ten segments. In Taylor's original description *A. bancrofti* was described as having nine segmented antennae, and all the specimens which I have examined exhibit this character. Tonnoir (1925) has amended this description and stated that the antennae are composed of ten segments, and hence he put the species in the genus *Austrosimulium.*

* In a letter Mr. A. L. Tonnoir has expressed doubt as to whether the antennae of the larvae are truly three-segmental. He suggests that the suture dividing the first and second segments may either be a trace of former segmentation or a fold due to telescoping of the segment before moulting. Personally, I am satisfied that there are three true segments present.

Taylor (1927) does not agree with this correction, and as all my specimens agree with his in this respect it seems probable that Tonnoir's specimens are exceptional.

Apart from the antennae there is no known adult character on which to separate the two genera, and therefore it is doubtful whether *A. bancrofti* should be retained in that genus. The male and early stages of this species are described for the first time in this paper.

Although *Simulium ornatipes,* Skuse, was one of the earliest known forms from Australia, the early stages have remained undescribed until now.

I also record a new species which I have named *Simulium tonnoiri,* n.sp., in compliment to Mr. A. L. Tonnoir, to whom I am greatly indebted for advice and aid in the matters of literature and named specimens.

Simulium ornatipes Skuse.

Skuse. Proc. Linn. Soc. N.S.W. 1890.

Tonnoir. Bull. Ent. Research. Vol. XV., Pt. 3, 1925.

Larva.—Length, 5-6 m.m.

Head.—Prefrons light with medium dark stripe from close to hind edge to just past the middle; two black spots near hinder end of stripe; and two smaller spots very close to it about 2/3rds of distance along it; rest of head capsule light except around the eyes and along the hinder edge laterally.

Antennae (Fig. 1, A) composed of three joints; second joint 1¼ times length of first; third joint shorter than 1st; two basal joints together as long as basal piece of the fan.

Submentum (Fig. 1, C) with three prominent teeth and between the central one and each lateral one are three small teeth.

Gill spots (Fig. 1, B) very large with an abrupt anterior ventral angle.

Body of greenish grey colour, darker posteriorly; two prominent ventral papillae at hinder end; anal gills simple; descending rods of anal armature bent out at lower end. Posterior sucker consists of numerous rows of 12-15 hooks.

Pupa.—Pupal gills (Fig. 1, D) consist of four stout filaments coming off as two pairs one above the other; basal horn very short; ventral filaments longer than dorsal ones.

Cocoon (Fig. 1, E).—Fairly open texture; applied to surface by ventral side; ventral wall of cocoon complete anteriorly and posteriorly, but absent in centre; prominent ventral rim at anterior end.

The cocoons and larvae are found attached to stones and other stationary objects, but more abundantly to grasses dipping in the water. The pupal period lasts 6-8 days.

This species does not seem to require a very fast current, and is more plentiful in the smaller streams.

Simulium tonnoiri, n.sp.

Male.

Length of body, 2.3 m.m.

Head.—Face brown, pubescence gold. Antennae composed of eleven joints; second segment brown, the rest yellow; 2nd and 3rd segments subequal about 1¼ times length of the 1st; 4th-10th joints sub-equal slightly

more than ½ length of 2nd; 11th joint as long as the 2nd. Mouth parts brown; 1st two palpal joints small and cyathiform; 3rd joint longer than 4th; 5th joint 2¼ times length of 4th.

Thorax.—Mesonotum brown or somewhat orange; darkened on medium rather broad band; pubescence short, golden, thicker anteriorly; scutellun with long yellow hair; pleurae light brown, two tufts of yellow hair present; mesosternum brown. Anterior and middle legs approximately equal; hind legs larger. Forelegs lighter in colour than others; mainly yellow and the pubescence yellow; tibia darkened at the base. Middle legs with femur and tibia both darkened near base; coxae dark, pubescence black and yellow. Hind legs similar colour but darkening more pronounced; metatarus produced into a distal internal lap of full width but narrowed at the base so as to produce a notch. Lap extends about two-thirds of length of 2nd joint. Claws with a basal tooth.

Wings.—Membrane clear except between *C* and *Sc* where it is yellow. *Cu* slightly undulating. A very distinct black stigma is formed by a thickening of *R* in region of its fork, of the cross vein *r-m*, and *M* just before it forks. Halteres yellowish.

Abdomen.—Black, pubescence yellow; basal side tufts long, yellow.

Genitalia (Fig. 2, A).—Basal segment of clasper stout, 2nd joint short and curved bearing two teeth at apex.

Female.

Length of body, 2.9 m.m.

Head.—Frons about 1/11th of width of the head; frons and face brown with yellow pubescence. Antennae with coloration as in male; first and second segments subequal; 3rd shorter; 11th slightly longer than 1st. Mouth parts brown; 1st joint longer and narrower than 2nd; 3rd joint slightly longer than fourth and 1½ times as wide; 5th joint twice length of 4th. The joints are stouter than the corresponding joints in the male.

Thorax.—As in the male; somewhat variable, some specimens being much darker than others. Legs as in male, but stouter. Claws with a prominent tooth at base.

Abdomen.—Similar to that of male.

Genitalia (Fig. 2, B).—Basal segment large; subgenital fork stout.

Types bred from pupae collected at Lesmurdie, 18/10/30.

Larva.—Length, 7-8 m.m.

Head.—Median dark line extends for more than halfway along prefrons; dark spot on either side of this line about middle of its length; dark coloration extends up beyond level of base of antennae; eyes in a clear space; capsule darkened posteriorly. Antennae (Fig. 3, A) composed of three joints; 1st joint slightly shorter than 2nd. 3rd is 1½ times length of 1st. Antennae slightly shorter than basal piece of fan.

Submentum (Fig. 3, C) with three prominent teeth; median one separated from each of lateral ones by three small teeth of which central one is smallest; outside each lateral tooth is a further large one at a lower level and separated from the former by three small teeth. Body, grey in colour but varies considerably.

Gill spots (Fig. 3, B) with a large ventral lobe. Posterior sucker is composed of numerous rows of from 18-24 hooks.

Pupa.—The pupal gills (Fig. 3, D) consist of 27-35 rigid filaments proceeding from three main trunks. The number of filaments is very variable, some having as many as 40, and others as few as 20. The terminal abdominal hooks are very large in this species.

Cocoon (Fig. 3, E).—Very rough, all sorts of foreign material being incorporated in its formation. The cocoon, which fits the pupa tightly, is applied to the support by its ventral surface if isolated but usually the cocoons are built in clumps of 10 or more, and in such cases they are attached to the support by their posterior ends only. The cocoons are found attached to stones but rarely to grasses. This species is equally common in slow and fast streams. It is obviously closely allied to *Simulium aurantiacum* Tonn. and resemblances between the two species are common in both adult and early stages. The adults can be recognised by the stigma in the wing. In life the upper portions of the eyes of the males are brilliant orange and the eyes of the female show a corresponding distribution of colour, but it is less pronounced.

These are the only two Australian species with branched pupal gills, but in *S. tonnoiri*, n.sp., the branching is more extensive.

Austrosimulium bancrofti, Taylor.*

F. H. Taylor, Australian Zoologist, Vol. 1, Pt. 6, 1918.

A. L. Tonnoir, Bull. Ent. Res., Vol. XV., Pt. 3, 1925.

F. H. Taylor, Bull. Ent. Res., Vol. XVIII., Pt. 1, 1927.

The female of this species has been described by Taylor from Queensland. As stated above, the condition of the antennae has provided some discussion, but all my specimens agree with the descriptions given by Taylor. The male and early stages are herewith described for the first time:—

Male.—Length, 1.8 m.m.

Head.—Black, mouth parts dark; pubescence grey. Antennae composed of nine segments; first three joints cyathiform; 2nd joint 1½ times length of 1st; 3rd joint 1½ times length of 2nd; 4th slightly smaller than 2nd; 5th-8th small, subequal; 9th nearly as long as 3rd, tapering.

Maxillary palps dark; 1st two joints small, 3rd enlarged proximally somewhat larger than 4th, which is swollen distally; 5th narrow, nearly twice length of 4th.

Thorax.—Velvety black, pubescence grey; hairs on scutellum long and black; pleurae grey. Anterior and middle legs approximately equal; coloration similar; coxae dark; femur and tibia darkened at base and tibia also darkened distally; tarsal joints dark, pubescence black. Hind legs larger, coxae light, otherwise coloration similar. Metatarsus has a slightly undulating anterior edge, produced distally into a short internal lap of only half width; lap projects only to one-fifth of length of 2nd tarsal joint and does not reach notch in latter. Claws with a tooth at the base. Wings.—*Cu* deeply curved. Halteres yellow.

* There is some doubt as to the correct identification of this species. The adult female appears to be indistinguishable from the type, but until the early stages have been described from the district in which the typs were collected, certainty cannot be reached.

I should also state that many of the new stages described in this paper have been known in the Eastern States by Mr. Tonnoir for some time, and that he has kindly allowed me to describe them. In all cases, however, the descriptions were made from West Australian material.

Abdomen.—Black, pubescence black and grey without ash grey spots as in the female; side tufts at base, grey.

Genitalia (Fig. 2, C).—Claspers long, 2nd segment slender, bearing four teeth.

Type bred from pupa collected at Serpentine, 16/4/30.

Larva.—Length, 5-6 m.m.

Head.—Rather light but depth of colour is variable; darkened on posterior margin, on a medium dorsal line and on thin line behind each eye. Antennae (Fig. 4, A) composed of three segments; 2nd joint 1⅓ times the 1st; 3rd slightly longer than 2nd. Antenna is slightly shorter than basal piece of fan.

Submentum (Fig. 4, C) with reduced teeth, only four project; two teeth between median tooth and each of outer large teeth.

Body.—Greenish grey in colour. Gill spot (Fig. 4, B) narrow, obliquely placed. Anal gills simple; from each of the dorsal expansions of the anal armature, a narrow rod runs to bases of the descending rods. Posterior sucker composed of rows of 20-25 teeth.

Pupa.—Gills (Fig. 4, D) consist of numerous narrow unbranched filaments given off from the base of a prominent projection with a papillose surface; projection extends beyond ends of filaments which are ringed at the base.

Cocoon (Fig. 4, E).—Transparent and membranous texture; it is set obliquely on its support by the posterior end, which is open; free end smaller and the edge is thickened.

The cocoons are found attached to stones and sticks but rarely to grasses This species is more abundant in fast flowing streams. The pupal period lasts from four to six days.

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EXPLANATION OF FIGURES.

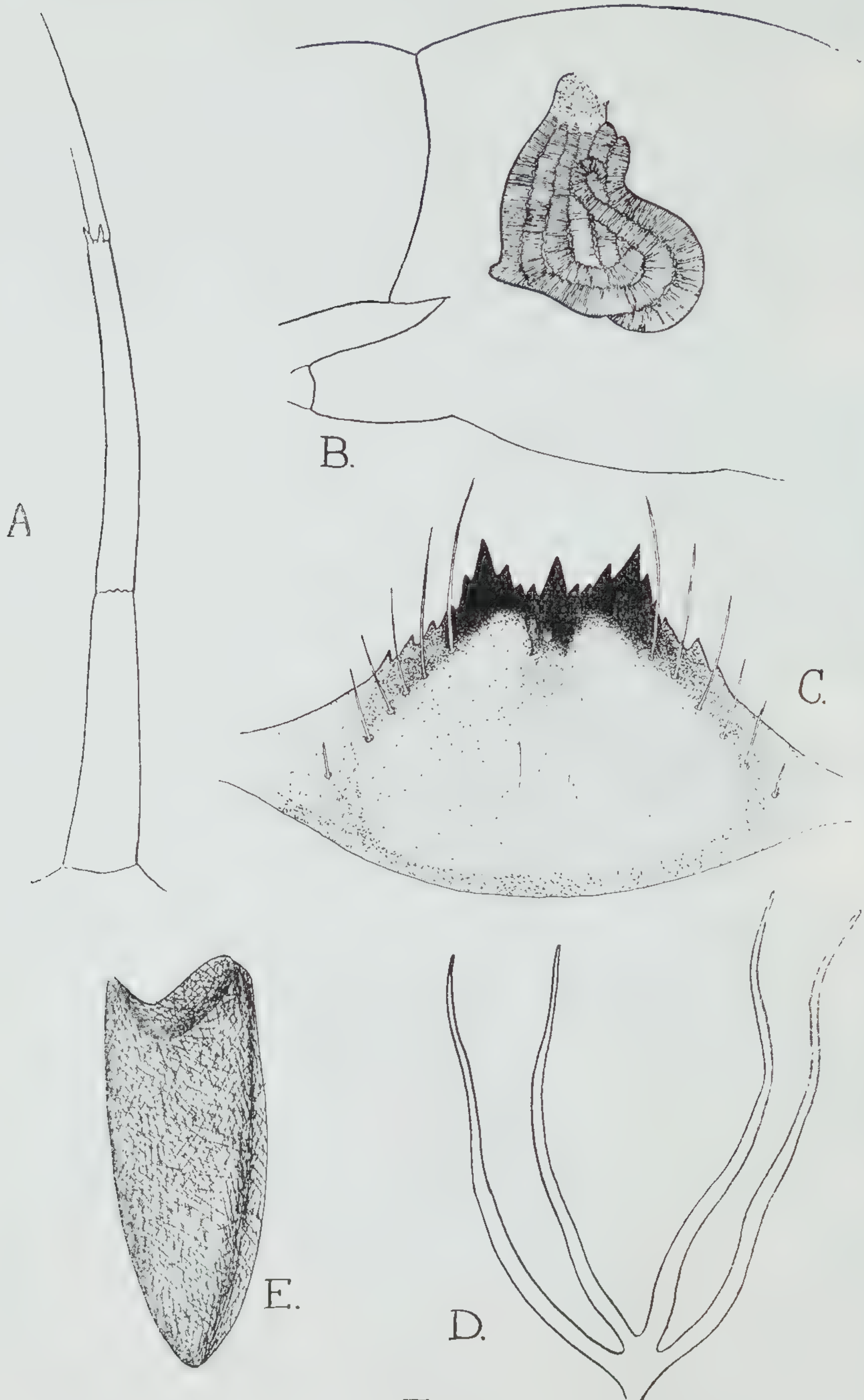

Fig. 1.

Fig. 1.—*Simulium ornatipes* Skuse. Larva.

A. antenna, B. gill spot, C. submentum, E. cocoon, D. pupal gills.

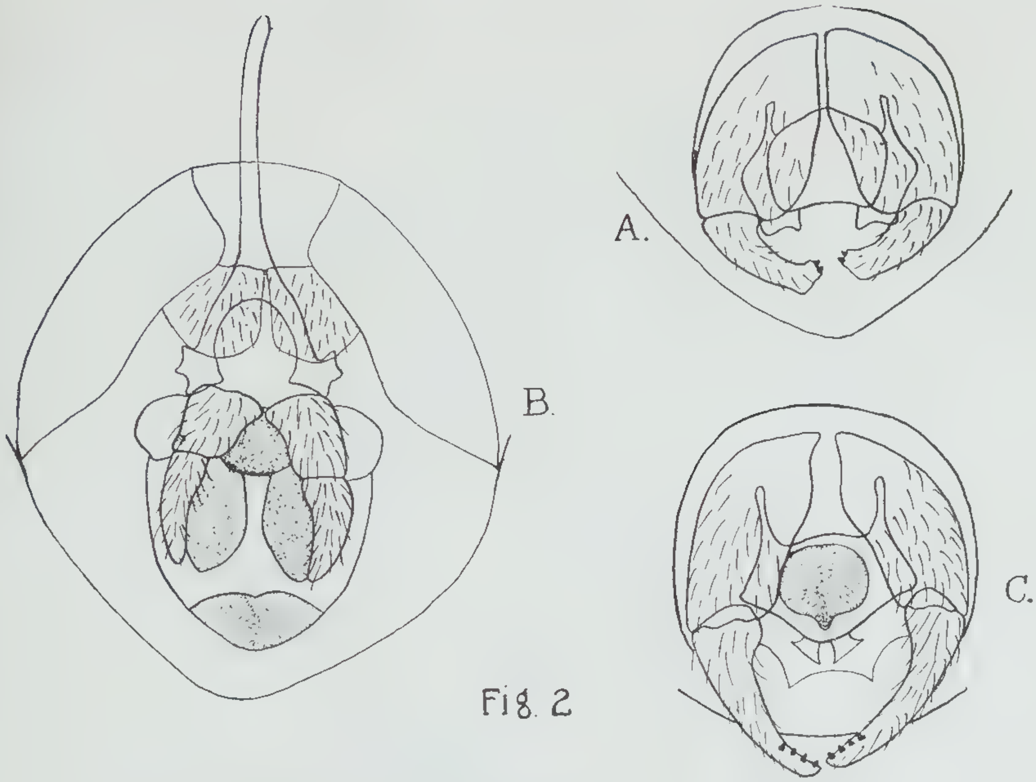

Fig. 2.—A. male genitalia of **Simulium tonnoiri** n.sp.
B. female genitalia of *Simulium tonnoiri* n.sp.
C. male genitalia of *Austrosimulium bancrofti* Taylor.

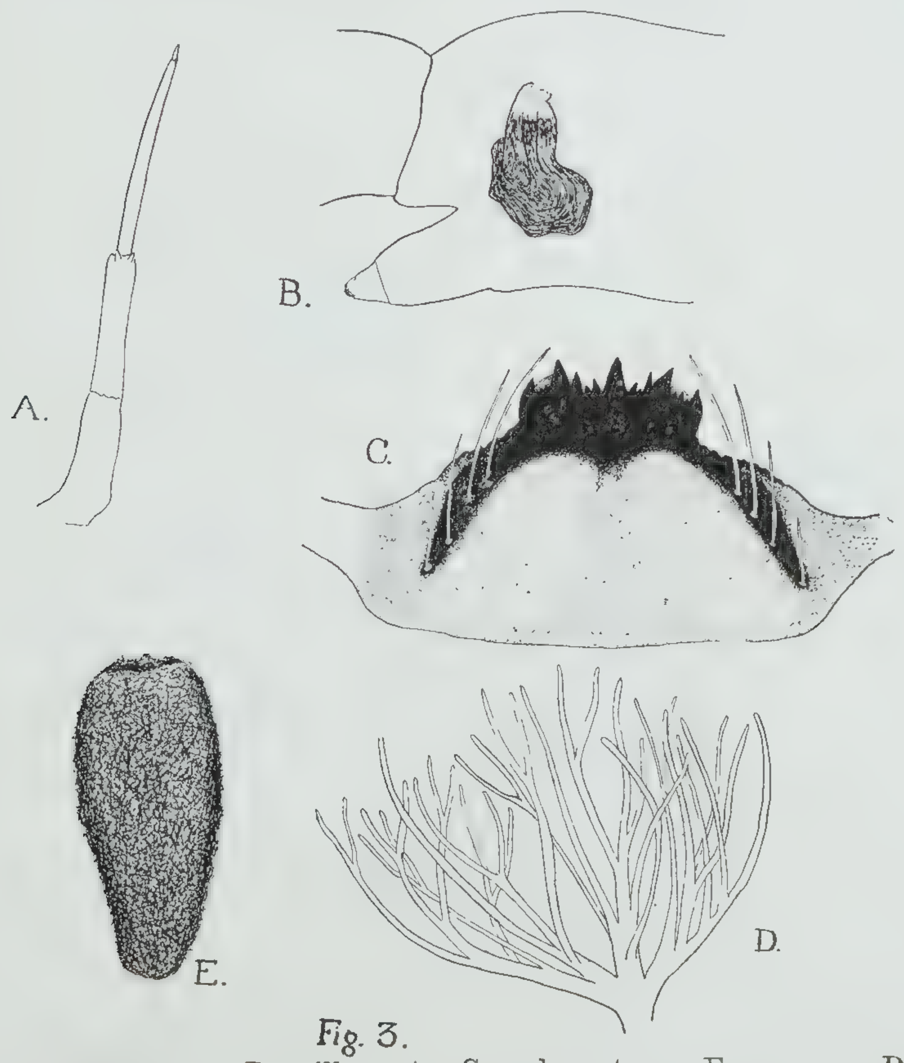

Fig. 3.—A. antenna, B. gill spot, C. submentum, E. cocoon, D. pupal gills.

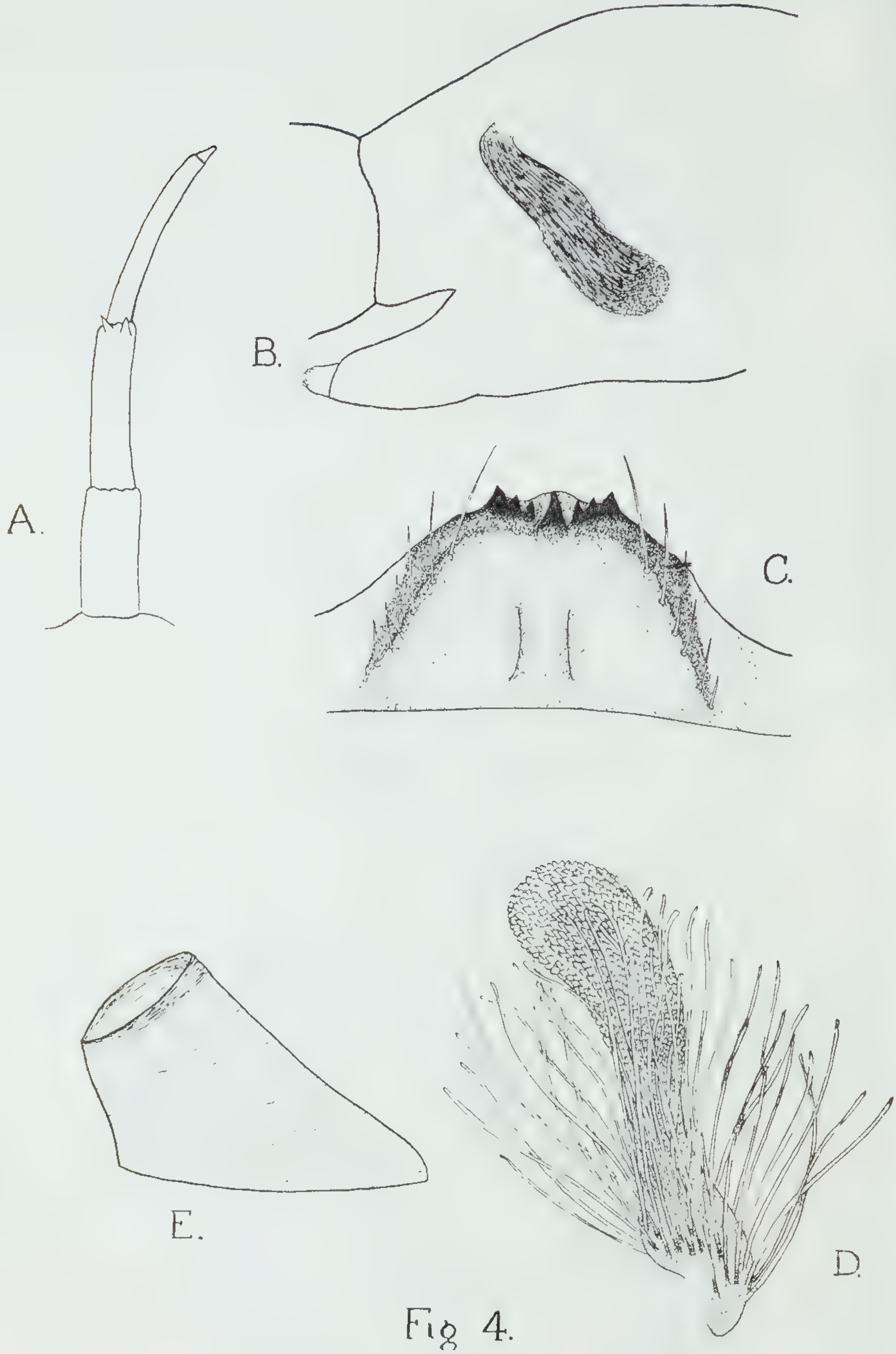

Fig. 4.—*Austrosimulium bancrofti* Taylor. Larva.

A. antenna, B. gill spot, C. submentum, E. cocoon, D. pupal gills.

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II.- AN INTRODUCTION TO THE WORRORA LANGUAGE.*

PART II.

By J. R. B. Love, B.A., M.C., D.C.M.

Read 12th August, 1930. *Published 2nd February*, 1932.

A typical transitive verb, Kungaw: I kill him (or I strike him).
The transitive verb is inflected to show subject and object.
Indicative mood, present tense, positive.

		him.	her.	it (wuna).	it (mana).
Singular.	I kill	kungaw	nyungaw	koongaw	mungaw
	You kill	kunjaw	nyinjaw	koonjaw	munjaw
	He or she kill ...	kaw	nyimbu	koombu	maw
Dual.	We two kill ...	karrwandu	nyarrwandu	worrwandu	marrwandu
	,, ,, ...	kehrwandu	nyehrwandu	koonyehrwandu	mehrwandu
	You two kill ...	kurrawandu	nyirawandu	kurawandu	marawandu
	They two kill ...	kawyundu	nyimbandu	koombandu	mawandu
Trial.	We three kill ...	karrwuri	nyarrwuri	worrwuri	marrwuri
	,, ,, ...	kehrwuri	nyehrwuri	koonyehrwuri	mehrwuri
	You three kill ...	kurrawuri	nyirawuri	kurawuri	marawuri
	They three kill ...	kawuri	nyimburi	koomburi	mawuri
Plural.	We many kill ...	karrwu	nyarrwu	worrwu	marrwu
	,, ,, ...	kehrwu	nyehrwu	koonyehrwu	mehrwu
	You many kill ...	kurraw	nyiraw	kuraw	maraw
	They many kill ...	kaueraw	nyimburrwu	kuburrwu	marwu

Note.—Explanation of above table:—
I kill him: kungaw; I kill her: nyungaw; I kill it (wuna): koongaw; I kill it (mana): mungaw.
E.g.—I kill a man: ija kungaw; I kill a woman: wongaiinya nyungaw; I kill a box tree: kauug koongaw; I kill a baobab tree: chungurim mungaw.

The verb kungaw: indicative mood, past tense, positive.

		him.	her.	it (wuna)	it (mana).
Singular.	I killed ...	kungawna	nyungawna	koongawna	mungawna
	You killed ...	kunjawna	nyinjawna	koonjawna	munjawna
	He killed ...	kawna	nyimbuna	koombuna	mawna
Dual.	We two killed	karrwunandu	nyarrwunandu	worrwunandu	marrwunandu
	,, ,,	kehrwunandu	nyehrwunandu	koonyehrwunandu	mehrwunandu
	You two killed	kurrawnandu	nyirawnandu	kurawnandu	marawnandu
	They two killed	kawnandu	nyimbunandu	koombunandu	mawnandu
Trial.	We three killed	karrwunori	nyarrwunori	worrwunori	marrwunori
	,, ,,	kehrwunori	nyehrwunori	koonyehrwunori	mehrwunori
	You three killed	kurrawnori	nyirawnori	kurawnori	marawnori
	They three killed	kawnori	nyimbunori	koombunori	mawnori
Plural.	We many killed	karrwuna	nyarrwuna	worrwuna	marrwuna
	,, ,,	kehrwuna	nyehrwuna	koonyehrwuna	mehrwuna
	You many killed	kurrawna	nyirawna	kurawna	marawna

* Part I. appeared in Vol. XVII., 1930–31, of this Journal.

Indicative mood, future tense, positive.

		him.	her.	it (wuna).	it (mana).
Singular.	I shall kill	ingaw	nyungaw	ngaw	mungaw
	You shall kill ...	injaw	nyinjaw	jaw	munjaw
	He shall kill	ehwu	nyehwu	nyaw	mehwu
Dual.	We two shall kill ...	arrawandu	nyarrawandu	worrawandu	marrawandu
	,, ,, ...	ehrawandu	nyehrawandu	nyehrawandu	mehrawandu
	You two shall kill ...	irehwandu	nyirehwandu	wurehwandu	marehwandu
	They two shall kill ...	ehwandu	nyehwandu	nyawandu	mehwandu
Trial.	We three shall kill ...	arrawuri	nyarrawuri	worrawuri	marrawuri
	,, ,, ...	ehrawuri	nyehrawuri	nyehrawuri	mehrawuri
	You three shall kill ...	irehwuri	nyirehwuri	wurehwuri	marehwuri
	They three shall kill ...	ehwuri	nyehwuri	nyawuri	mehwuri
Plural.	We many shall kill ...	arraw	nyarraw	worraw	marraw
	,, ,, ...	ehraw	nyehraw	nyehraw	mehraw
	You many shall kill ...	irehwu	nyirehwu	wurehwu	marehwu
	They many shall kill ...	ehwuraw	nyehwuraw	paraw	mehwuraw

The verb kungaw: negative forms.

Indicative mood, present tense, negative.

		him.	her.
Singular.	I do not kill	wa pungawn	wa pinyingawn
	You do not kill	,, punjawn	,, pinjawn
	He does not kill ...	,, punggawn	,, pinyimbeen
Dual.	We two do not kill ...	,, pudjawngundu	,, pinyingarwun-gundu
	,, ,, ,, ...	,, pejawngundu	,, pinyehrwun-gundu
	You two do not kill ...	,, purrawngundu	,, pinyirawn-gundu
	They two do not kill ...	,, punggawngundu	,, pinyimbeen-gundu
Trial.	We three do not kill ...	,, pudjawnguri	,, pinyingarwun-guri
	,, ,, ,, ...	,, pejawnguri	,, pinyehrwun-guri
	You three do not kill ...	,, purrawnguri	,, pinyirawn-guri
Plural.	We many do not kill ...	,, pudjawn	,, pinyingarwun
	,, ,, ,, ...	,, pejawn	,, pinyehrwun
	You many do not kill ...	,, purrawn	,, pinyirawn
	They many do not kill ...	,, pauerawn	,, pinyimburrwun

		it (wuna).	it (mana).
Singular.	I do not kill	wa poongawn	wa pummungawn
	You do not kill	,, pinjawn	,, pummunjawn
	He does not kill ...	,, poonggawn	,, pummawn
Dual.	We two do not kill ...	,, poongarwun-gundu	,, pummungarwun-gundu
	,, ,, ,, ...	,, pehrwun-gundu	,, pummehrwun-gundu
	You two do not kill ...	,, purawn-gundu	,, pummarawn-gundu
	They two do not kill ...	,, poonggawn-gundu	,, pummawn-gundu
Trial.	We three do not kill ...	,, poongarwun-guri	,, pummungarwun-guri
	,, ,, ,, ...	,, pehrwun-guri	,, pummehrwun-guri
	You three do not kill ...	,, purawn-guri	,, pummarawn-guri
	They three do not kill ...	,, poonggawn-guri	,, pummawn-guri
Plural.	We many do not kill ...	,, poongarwun	,, pummungarwun
	,, ,, ,, ...	,, pehrwun	,, pummehrwun
	You many do not kill ...	,, purawn	,, pummarawn
	They many do not kill ...	,, poonggarwun	,, pummarwun

The verb kungaw: negative forms.

Indicative mood, past tense, negative.

	him.	her.
I did not kill	wa pungawnya	wa pinyingawnya
	it (wuna).	it (mana).
I did not kill	wa poongawnya	wa pummungawnya

N.B.—(1) The negative forms throughout past tense are same as the present tense, with the addition of -ya.

N.B.—(2) The future negative forms are the same as the present tense with the future prefix picha.

N.B.—(3) The negative forms of the indicative are always prefixed by wa.

These same forms, without the prefix wa, are the *Obligatory Mood*, implying "must," or "ought."

E.g.—I do not kill him: wa pungawn.
I must kill him: pungawn.
Present tense, I do not kill him: wa pungawn.
Future tense, I shall not kill him: picha wa pungawn.
Past tense, I did not kill him: wa pungawnya.

The verb kungaw: subjunctive mood, present tense.

		him.	her.
Singular.	If (etc.) I kill	ingun-ngoombu	nyungun-ngoombu
	,, you kill	injungoonbu	nyinjungoonbu
	,, he kill	inggaw	nyunggaw
Dual.	,, we two kill ...	arkoombandu	nyarkoombandu
	,, ,, ,, ...	ehrkoombandu	nyehrkoombandu
	,, you two kill ...	irungoonbandu	nyirungoonbandu
	,, they two kill ...	inggawandu	nyirungoonbandu
Trial.	,, we three kill ...	arkoomburi	nyarkoomburi
	,, ,, ,, ...	ehrkoomburi	nyehrkoomburi
	,, you three kill ...	irungoonburi	nyirungoonburi
	,, they three kill ...	inggawuri	nyunggawuri
Plural.	,, we many kill ...	arkoombu	nyarkoombu
	,, ,, ,, ...	ehrkoombu	nyehrkoombu
	,, you many kill ...	irungoonbu	nyirungoonbu
	,, they many kill ...	inggarwu	nyunggarwu
		it (wuna).	it (mana).
Singular.	If (etc.) I kill	ngan-ngoombu	mungun-ngoombu
	,, you kill	choongoonbu	munjungoonbu
	,, he kill	kumminyaw	munggaw
Dual.	,, we two kill ...	workoombandu	markoombandu
	,, ,, ,, ...	nyehrkoombandu	mehrkoombandu
	,, you two kill ...	wurungoonbandu	marungoonbandu
	,, they two kill ...	koombandu	munggawandu
Trial.	,, we three kill ...	workoomburi	markoomburi
	,, ,, ,, ...	nyehrkoomburi	mehrkoomburi
	,, you three kill ...	wurungoonburi	marungoonburi
	,, they three kill ...	koomburi	munggawuri
Plural.	,, we many kill ...	woraw	markoombu
	,, ,, ,, ...	nyehraw	mehrkoombu
	,, you many kill ...	wurungoonbu	marungoonbu
	,, they many kill ...	purraw	munggarwu

The verb kungaw: subjunctive mood, past tense.

		him.	her.
Singular.	If (etc.) I killed	ingun-ngoombuna	nyungun-ngoombuna
	,, you killed	injungoonbuna	nyinjungoonbuna
	,, he killed	inggawna	nyunggawna
Dual.	,, we two killed ...	arkoombunandu	nyarkoombunandu
	,, ,, ,, ...	ehrkoombunandu	nyehrkoombunandu
	,, you two killed ...	irungoonbunandu	nyirungoonbunandu
	,, they two killed ...	inggawnandu	nyunggawnandu
Trial.	,, we three killed ...	arkoombunori	nyarkoombunori
	,, ,, ,, ...	ehrkoombunori	nyehrkoombunori
	,, you three killed ...	irungoonbunori	nyirungoonbunori
	,, they three killed ...	inggawnori	nyunggawnori
Plural.	,, we many killed ...	arkoombuna	nyarkoombuna
	,, ,, ,, ...	ehrkoombuna	nyehrkoombuna
	,, you many killed ...	irungoonbuna	nyirungoonbuna
	,, they many killed ...	inggarwuna	nyunggarwuna

N.B.—(1) Forms for past tense, subjunctive, with neuter objects wuna and mana, are similarly formed from present tense.

E.g.—Ngan-ngoombuna: if I killed it (wuna).
Mungun-ngoombuna: if I killed it (mana).

N.B.—(2) The subjunctive mood is used in subsidiary clauses, *i.e.*, clauses introduced by hypothetical words, such as ngumba: "if," wunawmurum: "when"; and Clauses dependent on another verb.

E.g.—If I kill him: ngaiu ngumba ingun-ngoombu.
When he killed him: wunawmurum inggawna.
He knew that he killed him: laibiru kunnina aua inggawna.

N.B.—(3) The subjunctive occurs only in present and past tenses. Clauses that would be future are expressed by the indicative mood.

E.g.—If he shall kill him: aua ngumba picha ehwu.

The verb kungaw: potential mood (present tense only).

The *potential mood* expresses "can" or "might."

"Can" is preceded by golleh: ("complete," or "finished").

"Might" takes the word ngunna (euphonically becomes kunna after some word endings), either before or after the verb. Sometimes ngunna may be omitted.

E.g.—I can kill a fish (fish is masculine): jaia golleh pungaw.
I might kill a fish: jaia pungaw ngunna; jaia ngunna pungaw; jaia pungaw.

		him.	her.	it (wuna).	it (mana).
Singular.	I can kill	pungaw	pinyingaw	poongaw	pummungaw
	You can kill ...	punjaw	pinjaw	pinjaw	pummunjaw
	He can kill ...	punggaw	pinyimbu	poonggaw	pummaw
Dual.	We two can kill ...	purrwandu	pinyingarwandu	poongarwandu	pummungarwandu
	,, ,, ,, ...	pehrwandu	pinyehrwandu	pinyehrwandu	pummehrwandu
	You two can kill ...	purrawandu	pinyirawandu	pirawandu	pummurrawandu
	They two can kill ...	punggawandu	pinyimbandu	poonggawandu	pummawandu
Trial.	We three can kill ...	purrwuri	pinyingarwuri	poonggarwuri	pummungarwuri
	,, ,, ,, ...	pehrwuri	pinyehrwuri	pinyehrwuri	pummehrwuri
	You three can kill ...	purrawuri	pinyirawuri	pirawuri	pummarawuri
	They three can kill...	punggawuri	pinyimburi	poonggawuri	pummawuri
Plural.	We many can kill ...	parrwu	pinyingarwu	poongarwu	pummungarwu
	,, ,, ,, ...	pehrwu	pinyehrwu	pinyehrwu	pummehrwu
	You many can kill ...	paraw	pinyiraw	puraw	pummaraw
	They many can kill	paueraw	pinyimburrwu	poonggarwu	pummarwu

N.B.—The potential mood occurs only in present tense.

The verb kungaw : *imperative mood.*

			him.	her.	it (wuna).	it (mana).
Singular.	1.	Let me kill ...	kungawnya	nyungawnya	koongawnya	mungawnya
	2.	You kill	iwu	nyimbu	minyaw	maw
	3.	Let him kill ...	kawnya	nyimbeenya	koombeenya	mawnya
Dual.	1a.	Let us two kill ...	arrwandu	nyarrwandu	worrwandu	marrwandu
	1b.	Let us two kill ...	ehrwandu	nyehrwandu	koonyehrwandu	mehrwandu
	2.	You two kill ...	irawandu	nyirawandu	wurawandu	marawandu
	3.	Let them two kill ...	kawnyandu	nyimbeenyandu	koombeenyandu	mawnyandu
Trial.	1a.	Let us three kill ...	arrwuri	nyarrwuri	worrwuri	marrwuri
	1b.	,, ,, ,, ...	ehrawuri	nyehrawuri	nyehrawuri	mehrwuri
	2.	You three kill ...	irawuri	nyirawuri	wurawuri	marawuri
	3.	Let them three kill	kawnyuri	nyimbeenyuri	koombeenyuri	mawnyuri
Plural.	1a.	Let us many kill ...	arrwu	nyarrwu	worrwu	marrwu
	1b.	,, ,, ,, ...	ehraw	nyehraw	nyaraw	megraw
	2.	You many kill ...	iraw	nyiraw	wuraw	maraw
	3.	Let them many kill	kauerawnya	nyimburrweenya	kuburrweenya	marweenya

The imperative is also inflected for plural objects as follows :—

	one.	two.	three.	many.
Let me kill ...	kungawnya	ingawandu	ingawuri	unguminyaw
You kill	iwu	iwandu	iwuri	unyaw, etc.

The verb kungaw : *passive voice*, indicative mood, positive.

E.g.—I am killed : ngauingu ; I was killed : ngauina ; I shall be killed : ngehwi.

		Present tense.	Past tense.	Future tense.
Singular.	1st	ngauingu	ngauina	ngehwi
	2nd	ngoombingu	ngoombina	ngoonyehwi
	3rd m.	kauingu	kauina	ehwi
	,, f.	nyimbingu	nyimbina	nyehwi
	,, n.w.	koombingu	koombina	nyawi
	,, n.m.	mauingu	mauina	mehwi
Dual.	1st a.	ngarwingandu	ngarwinandu	ngarawiundu
	,, b.	arwingandu	arwinandu	arawiundu
	2nd	nyirwingandu	nyirwinandu	nyirawiundu
	3rd m.	kauingandu	kauinandu	ehwiundu
	,, f.	nyimbingandu	nyimbinandu	nyirawiundu
	,, n.w.	koombingandu	koombinandu	nyawiundu
	,, n.m.	mauingandu	mauinandu	mehwiundu
Trial.	1st a.	ngarwinguri	ngarwinuri	ngarawiuri
	,, b.	arwinguri	arwinuri	arawiuri
	2nd	nyirwinguri	nyirwinuri	nyirawiuri
	3rd m.	kauinguri	kauinuri	ehwiuri
	,, f.	nyimbinguri	nyimbinuri	nyehwiuri
	,, n.w.	koombinguri	koombinuri	nyawiuri
	,, n.m.	mauinguri	mauinuri	mehwiuri
Plural.	1st a.	ngarwingu	ngarwina	ngarawi
	,, b.	arwingu	arwina	arawi
	2nd	nyirwingu	nyirwina	nyirawi
	3rd m. and f. ...	karwingu	karwina	arawi
	,, n.w. and m. ...	same as singular.		

The verb kungaw: passive voice, negative, indicative mood.

E.g.—I am not killed: wa pungaween.

I was not killed: wa pungaweenya.

The future negative passive is same as the present; *e.g.*, I shall not be killed: picha wa pungaween.

		Present tense.	Past tense.
Singular.	1st ...	wa pungaween	wa pungaweenya
	2nd ...	,, poongoonbeen	,, poongoonbeenya
	3rd m.	,, punggaween	,, punggaweenya
	,, f.	,, pinyimbeen	,, pinyimbeenya
	,, n.w.	,, poonggaween	,, poonggaweenya
	,, n.m.	,, pummaween	,, pummaweenya
Dual.	1st a.	,, purrwin-gundu	,, purrwinyandu
	,, b.	,, pehrwin-gundu	,, pehrwinyandu
	2nd ...	,, pinyirwin-gundu	,, pinyirwinyandu
	3rd m.	,, punggawin-gundu	,, punggawinyandu
	,, f.	,, pinyimbin-gundu	,, pinyimbinyandu
	,, n.w.	,, poonggawin-gundu	,, poonggawinyandu
	,, n.m.	,, pummawin-gundu	,, pummawinyandu
Trial.	1st a.	,, purrwin-guri	,, purrwinyuri
	,, b.	,, pehrwin-guri	,, pehrwinyuri
	2nd ...	,, pinyirwin-guri	,, pinyirwinyuri
	3rd m.	,, punggawin-guri	,, punggawinyuri
	,, f.	,, pinyimbin-guri	,, pinyimbinyuri
	,, n.w.	,, poonggawin-guri	,, poonggawinyuri
	,, n.m.	,, pummawin-guri	,, pummawinyuri
Plural.	1st a.	,, pungarween	,, pungarweenya
	,, b.	,, pehrween	,, pehrweenya
	2nd ...	,, pinyirween	,, pinyirweenya
	3rd m.	,, parween	,, parweenya
	,, f.	,, same as masculine.	
	,, n.w. and m.	,, same as singular.	

The verb kungaw: passive voice, *subjunctive mood*.

The subjunctive mood occurs only in present and past tenses.

E.g.—If I am killed: ngumba ngan-ngoombingu.

If I were (or had been), killed: ngumba ngan-ngoombina.

If I shall be killed: ngumba picha ngan-ngoombingu.

		Present tense.	Past tense.
Singular.	1st ...	ngan-ngoombingu	ngan-ngoombina
	2nd ...	ngoon-ngoombingu	ngoon-ngoombina
	3rd m.	inggawingu	inggawinya
	,, f.	nyunggawingu	nyunggawinya
	,, n.w.	kauingu	kauinya
	,, n.m.	munggawingu	munggawinya
Dual.	1st a.	ngarkoombingandu	ngarkoombinyandu
	,, b.	arkoombingandu	arkoombinyandu
	2nd ...	nyirkoombingandu	nyirkoombinyandu
	3rd m.	inggawingandu	inggawinyandu
	,, f.	nyunggawingandu	nyunggawinyandu
	,, n.w.	kauingandu	kauinyandu
	,, n.m.	munggawingandu	munggawinyandu
Trial.	1st a.	ngarkoombinguri	ngarkoombinyuri
	,, b.	arkoombinguri	arkoombinyuri
	2nd ...	nyirkoombinguri	nyirkoombinyuri
	3rd m.	inggawinguri	inggawingyuri
	,, f.	nyunggawinguri	nyunggawinyuri
	,, n.w.	kauinguri	kauinyuri
	,, n.m.	munggawinguri	munggawinyuri
Plural.	1st a.	ngarkoombingu	ngarkoombinya
	,, b.	arkoombingu	arkoombinya
	2nd ...	nyirkoombingu	nyirkoombinya
	3rd m.	unggawingu	unggawinya
	,, f.	same as masculine.	
	,, n.w. and m.	same as singular.	

The verb kungaw : passive voice, *potential mood.*

E.g.—I might be killed : ngaiu ngunna pungawi, or pungawi, or pungawi ngunna.

The potential mood occurs only in present tense.

N.B.—The past tense uses subjunctive forms with ngunna ; *e.g.*, I might have been killed : ngan-ngoombingu ngunna.

Singular.	1st	... ...	pungawi
	2nd	... ...	poongoonbi
	3rd m.	... ...	punggawi
	,, f.	... ...	pinyimbi
	,, n.w.	... ...	poonggawi
	,, n.m.	... ...	pummawi
Dual.	1st a.	... ...	pungarwiundu
	,, b.	... ...	pehrwiundu
	2nd	... ...	pinyiriundu
	3rd m.	... ...	punggawiundu
	,, f.	... ...	pinyimbiundu
	,, n.w.	... ...	poonggawiundu
	,, n.m.	... ...	pummawiundu
Trial.	1st a.	... ...	pungarwiwiri
	,, b.	... ...	pehrwiwiri
	2nd	... ...	pinyirwiwiri
	3rd m.	... ...	punggawiwiri
	,, f.	... ...	pinyimbiwiri
	,, n.w.	... ...	poonggawiwiri
	,, n.m.	... ...	pummawiwiri
Plural.	1st a.	... ...	pungarwi
	,, b.	... ...	pehrwi
	2nd	... ...	pinyirwi
	3rd m. & f.	... ...	parwi
	,, n. w. & m.	... ...	same as singular

The verb kungaw : *object in first and second persons.*

Positive.

		me	you
Singular	I kill	. . . . . .	ngoonbu
	You kill	chanbu	. . . . . .
	He (or she) kills ...	nganbu	ngoonbu
Dual.	We two kill	. . . . . .	ngoonburrwandu
	You two kill	charawandu	. . . . . .
	They two kill	nganbandu	ngoonbandu
Trial.	We three kill	. . . . . .	ngoonburrwuri
	You three kill	charawuri	. . . . . .
	They three kill ...	nganburi	ngoonburi
Plural.	We many kill	. . . . . .	ngoonburrwu
	You many kill	charaw	. . . . . .
	They many kill ...	nganburrwu	ngoonburrwu

Negative.

		me	you
Singular	I do not kill	. . . . . .	Wa poongoonboon
	You do not kill	Wa punyanboon	. . . . . .
	He does not kill	,, punganboon	,, poongoonboon
Dual.	We two do not kill	,, ...	,, poongoonburrwun-gundu
	You two do not kill	,, punyarawn-gundu	. . . . . .
	They two do not kill	,, punganboon-gundu	,, poongoonboon-gundu
Trial.	We three do not kill	,, ...	,, poongoonburrwun-guri
	You three do not kill	,, punyarawn-guri	,, ...
	They three do not kill	,, punganboon-guri	,, poongoonboon-guri
Plural.	We many do not kill	,, ...	,, poongoonburrwun
	You many do not kill	,, punyarawn	,, ...
	They many do not kill	,, punganbarrwun	,, poongoonburrwun

The verb kungaw: *object in first and second persons,* past tense.

Positive.

		me	you
Singular.	I killed	. . . . . .	ngoonbuna
	You killed	chanbuna	. . . . . .
	He killed	nganbuna	ngoonbuna
Dual.	We two killed	. . . . . .	ngoonburrwunandu
	You two killed ...	charawnandu	. . . . . .
	They two killed ...	nganbunandu	ngoonbunandu
Trial.	We three killed ...	. . . . . .	ngoonburrwunori
	You three killed ...	charawnori	. . . . . .
	They three killed ...	nganbunori	ngoonbunori
Plural.	We many killed ...	. . . . . .	ngoonburrwuna
	You many killed ...	charawna	. . . . . .
	They many killed ...	nganburrwuna	ngoonburrwuna

Negative.

		me	you
Singular.	I did not kill	. . . . . .	Wa poongoonbinya
	You did not kill	Wa punyanbinya	,, ...
	He did not kill...	,, punganbinya	,, poongoonbinya
Dual.	We two did not kill	,, ...	,, poongoonburrwinyandu
	You two did not kill	,, punyarawnyandu	,, ...
	They two did not kill	,, pungunbinyandu	,, poongoonbinyandu
Trial.	We three did not kill	,, ...	,, poongoonburrwinyuri
	You three did not kill	,, punyarawnyuri	,, ...
	They three did not kill	,, punganbinyuri	,, poongoonbinyuri
Plural.	We many did not kill	,, ...	,, poongoonburrwinya
	You many did not kill	,, punyarawnya	,, ...
	They many did not kill	,, punganburrwinya	,, poongoonburrwinya

The verb kungaw: *object in first and second persons, future tense.*

Positive.

		me.	you.
Singular.	I shall kill	. . . . . .	ngoonyaw
	You will kill	chanyaw	. . . . . .
	He will kill	nganyaw	ngoonyaw
Dual.	We two shall kill ...	. . . . . .	ngoonburrawandu
	You two will kill ...	charehwandu	. . . . . .
	They two will kill ...	nganyawandu	ngoonyawandu
Trial.	We three shall kill ...	. . . . . .	ngoonburrawuri
	You three will kill ...	charehwuri	. . . . . .
	They three will kill ...	nganyawuri	ngoonyawuri
Plural.	We many shall kill ...	. . . . .	ngoonburraw
	You many will kill ...	charehwu	. . . . .
	They many will kill ...	nganburraw	ngoonburraw

Negative future is the same as the present.

The transitive verb is also inflected to show objects in dual, trial, and plural numbers.

E.g.,	I kill one (masc.)	kungaw
	I kill two	kungawandu
	I kill three	kungawuri
	I kill many	kangaw
	I kill you, one	ngoonbu
	I kill you, two	nyinbandu
	I kill you, three	nyinburi
	I kill you, many	nyinbu

The typical transitive verb *kungaw*: I kill.

Summary of the moods.

The *indicative* expresses oratio recta and simple statement of fact. *E.g.*, I kill him: kungaw.

The *negative indicative* is preceded by wa.

E.g.—I do not kill him: wa pungawn.

The *obligatory* expresses "must," or "ought." Forms as negative, without wa.

E.g.—I must kill him, or I ought to kill him: pungawn.

The *subjunctive* expresses the verb is a subsidiary clause; *i.e.*, a clause introduced such a word as "if" or "when", or a clause dependent upon another verb.

E.g.—If I kill him: ngaiu ngumba ngan-ngoombu.
You know I killed him: laibiru ngunoong ngan-ngoombuna.

The *potential* expresses "can" or "might." "Can" is preceded by golleh; "might" usually takes ngunna before or after the verb.

E.g.—I can kill him: Ngaiu golleh pungaw.
I might kill him: pungaw ngunna.

The *imperative* expresses command or entreaty, in all three persons.

E.g.—Let me kill him: kungawnya.
You kill him: iwu.
Let him kill him: kawnya.

The *infinitive* does not exist as an infinitive. Worrora states the subject and object of each transitive verb. Where the subject and object are stated, an infinitive rendering can be stated by adding the word *woonya*: "to," or "for the purpose of," to the verb.

E.g.—I wish to kill him: lai-kauonara *ingaw woonya*. (N.B.—Here the verb is placed in the future tense.)

Notes on the conjugations of the *verb*.

I.—The verb "to be" appears in combination with such words as the following:—achu-nganoong: I sit down or I remain; bari-nganoong: I arise; baru-baru-nganoong: I dream; laibiru-nganoong: I know; ngoiba-nganoong: I rest; nguru-nganoong: I listen; (*c.f.*, nguru-kungaw: I hear him); pai-nganoong: I ascend; yir-nganoong: I pull.

II.—The verb kungaw: "I kill him," or "I strike him," appears in such combinations as chipah-kungaw: I spit on him; mara-kungaw: I see him; nguru-kungaw: I hear him.

Conjugated similarly to kungaw are such transitive verbs as kunganaw: I give to him (kunjanaw, kunnaw, etc.); kungawn ju: I tempt him; kunganguru: I take him away; kunganju: I make him; kungaiindiweh: I leave him. These verbs contain the idea of action upon an object at some distance, and so *cf.*, the pronoun inaw: he-over-there.

A class of verbs similar to kungaw is of those based on the predicate kungum; *e.g.*, charawud-kungum: I lift; manuk-kungum: I carry. These verbs contain the idea of action of the hands of the agent towards himself.

Another similar class is of those based on the predicate kungi; brai-kungi: I put up; tai-kungi: I put on him. These contain the idea of action of the hands of the agent away from his body.

III.—The *intransitive verbs* are, apart from the use of the verb "to be" (which includes transitive and intransitive), mostly based on the two words "go" and "fall."

The scheme of the conjugations of these is similar to nganoong.

E.g.—Ngenga : I go ; ngoonyunga : you go ; kenga : he goes, etc.

Ngauona : I call ; ngoonbunna : you fall ; kauona : he falls, etc.

Widaua ngenga : I walk ; jaw ngenga : I drink ; lai-kauonara : I like.

(Lai-kauonara : I like. Literally : "liking falls to me".)

IV.—A class of verbs that is intransitive in English is found, on examination, in Worrora, to be an impersonal transitive use, of kungaw.

E.g.—Baia-nganbu : I hunger ; boonggara-nganbu : I thirst ; kulunu-nganbu : I am sleepy. Literally these verbs are "hunger strikes me" ; "thirst strikes me," etc.

(N.B.—Kulunu-nganbu : I am sleepy, compare with kulunu-nganoong : I am sleeping.)

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3.—THE PHYSIOGRAPHY AND GEOLOGY OF THE UPPER SWAN AREA.

by

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I.—INTRODUCTION.

The Upper Swan Area, situated about twenty-five miles north-north-west of Perth on the edge of the Darling peneplain, covers an area of about five square miles. It is drained by portions of the Swan and Gatta Rivers and their tributaries.

Most of the field work was done by the authors in 1929 as part of the course in Honours Geology at the University of Western Australia, but in 1926 K. Finucane and F. G. Forman devoted some time to preliminary survey work in the area, this being necessary owing to the scarcity of survey data. Between 1926 and 1929 and also during the authors' stay, various

students, under the leadership of Professor E. de C. Clarke, contributed towards the mapping of the area.

One of us (R.W.F.) is entirely responsible for the igneous and metamorphic petrology.

The work was done under the supervision of Professor E. de C. Clarke, to whom we wish to express our indebtedness.

The rainfall and vegetation of the area are similar to those of the Darlington Area (Clarke & Williams, 1926, p. 163).

II.—PHYSIOGRAPHY.

General Relief.

The model (Plate II.) constructed from the form-line map, of which Plate I. is a reduction, shows that the area consists of four dissected blocks of high relief, carved out of the western edge of the Darling Peneplain (Jutson, 1914, p. 42), the eastern blocks being separated from the western blocks by the Swan River, and from each other by the Gatta which meets the Swan in the centre of the area. The western half of the area is also divided into two blocks by a wide flat alluvium-covered saddle.

Rivers and their Tributaries.

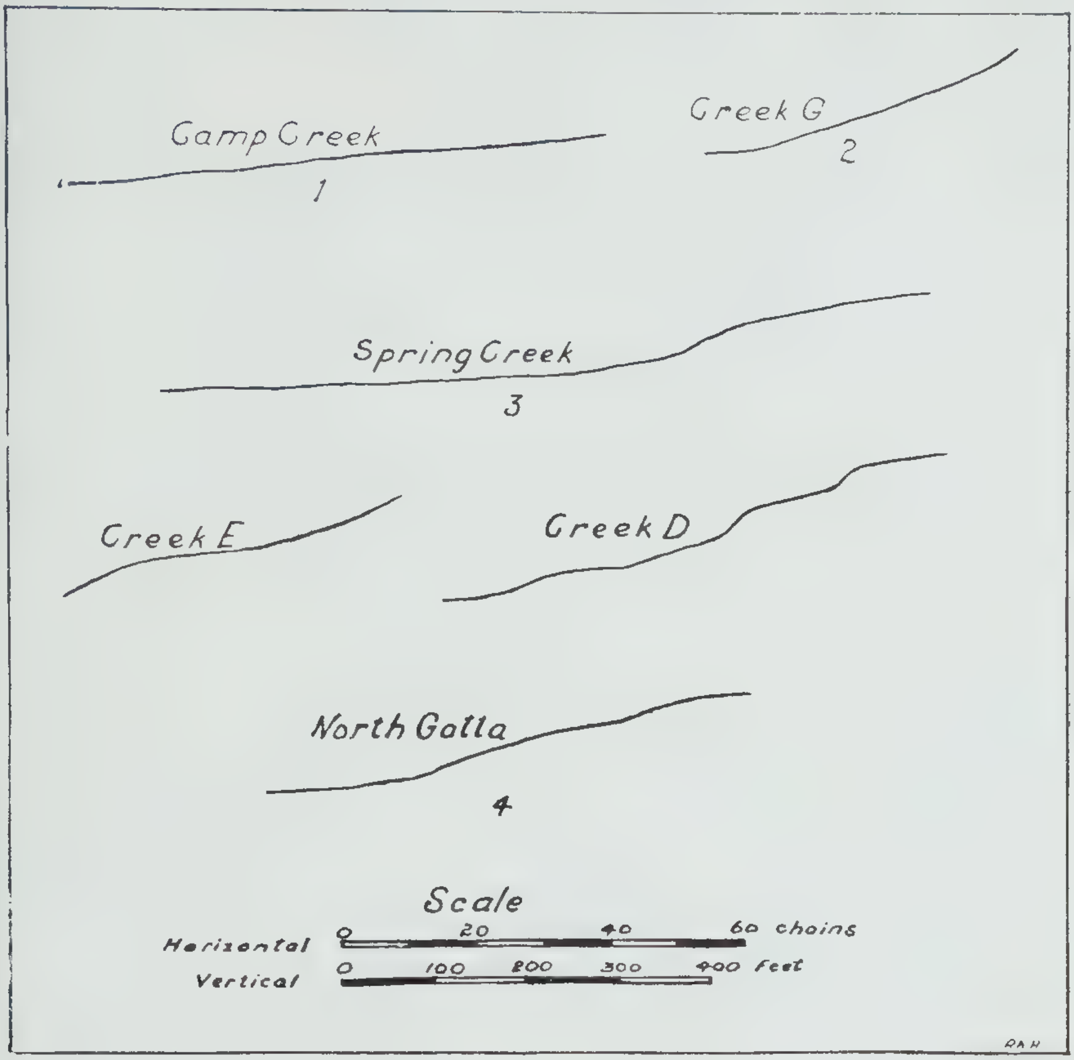
The Swan River flows through the area in a general southerly direction, except in the central part of the area where it is joined by the Gatta and takes a sharp bend to the west. The valley follows a zone of shearing and at many points along the valley a banded gneiss has been found. The bed of the Swan rises only 27 feet throughout its length in the area (about two miles) and at the lowest point is 98 feet above sea level. During the summer months the water course is occupied only by a series of pools—one of which, above the junction of the Gatta and Swan, is of considerable size. Soon after the first heavy rain the Swan begins to flow and in the winter months is a strong stream. In 1929 flow began on Saturday, 4th May, a few days after the first heavy rains.

The Swan flows out of the area through a fairly steep-sided valley, the western side of which is steeper than the eastern side. Looking at the western side from the eastern side of the valley a line of cliffs can be seen at about the 450 foot level extending parallel to the direction of the valley. If the line of these cliffs were produced, it would intersect a cliff in the valley of Creek D and also a scarp beyond the southern boundary of the area. It is suggested that this may be a line of faulting.

The South Gatta or Wooroloo Brook rises some considerable distance inland and only about 1½ miles of its course lies in the Upper Swan Area. The South Gatta flows through a fairly steep-sided valley and from where it enters the area to where it joins the Swan River there is a fall of 100 feet which is much greater than the fall in the Swan Valley. The South Gatta, just before joining the Swan, flows through a deep trench with steep sides which contrasts with the flatter nature of the stream bed higher up the valley.

At the junction of the Swan and Gatta Rivers there is a considerable amount of recent alluvium and on the west bank of the Swan a steep cliff has been formed.

Tributaries flowing into the Swan and the Gatta may be divided into four main types which are illustrated in text figure 1.



Text figure 1.—PROFILES OF CREEKS IN UPPER SWAN AREA.

(1) Tributaries which have a flat and fairly constant grade throughout their entire length. Camp Creek is the only representative of this class. While the general profile of Camp Creek is flat there are several places where it flows over small cliffs.

(2) Tributaries which have a steep grade throughout their length. Such streams occupy narrow V-shaped valleys. To this class belong Creeks G and H and those streams flowing south into Spring Creek. Also, most of the small tributaries may be included here with the exception of two small streams flowing into the Swan, north of Creek E, which do not enter at grade.

(3) Tributaries which before entering the main stream flow over a flattened area, but which become steeper towards their source. The best example of this type is Spring Creek which originates in the N.W. portion of the area, flows in a southerly direction for just over half a mile through a steep-sided valley in which there are a number of small waterfalls, then turns S.E., meanders in alluvium for a mile, before joining the Swan. Other streams belonging to this type are Creek F and in a lesser way, Creek M and others.

(4) Streams which show one or more changes in grade throughout their lengths other than those noted in (3) above. Creeks D, E and the North Gatta belong to this type. Near to the East boundary of the area the North Gatta flows through a deep steep-sided valley.

Springs.

Springs occur at three places in the area, and in the summer months they are the only supplies of fresh water available. They are found near the camp, in the N.W. corner in Spring Creek and also in Camp Creek. In Spring Creek they occur in areas of sheared granite, but in Camp Creek the rocks are quite massive. The spring near the camp occurs in an area of alluvium and hence it cannot be seen whether or not the underlying older rocks are sheared.

Terraces.

Although flattened areas can be distinguished at 300, 400, 500, and 650 feet above sea level, they are too numerous and inconspicuous to justify correlation with those occurring at 250 and 450 feet above sea level in the valley of the Helena River. (Clarke & Williams, 1926, p. 167).

III.—GEOLOGY AND PETROLOGY.

Field Distribution of Rocks.

The country rock of the Upper Swan Area is granite, which is concealed in places by accumulations of duricrust and of alluvium. Duricrust (term suggested by Woolnough, 1927, p. 24) occurs at two very distinct levels—above the 700 foot on the flat-topped plateau remnant in the north-east portion of the area, and about the 200-350 feet levels in the western and central portions of the area. The high level duricrust is seen to grade downwards directly into granite, but at lower levels the duricrust is associated with alluvium and what may be referred to as a ferruginous sandstone. More will be said about this later. This ferruginous sandstone has also been found associated with the high level duricrust, but in much smaller quantities.

The alluvium covers a considerable portion of the area and is characterised by the occurrence of well rounded quartz pebbles. The distribution of this alluvium has been indicated on the map and model (Plates I. and II.). It is difficult, however, to mark an exact boundary, but alluvium has been indicated wherever these rounded quartz pebbles are known to occur. Further, no distinction has been made between the very recent alluvium of the Swan and Gatta Rivers and the older alluvium occurring at higher levels than those of the present rivers.

Outcropping through the alluvium in the valley of the Swan is a belt of banded gneiss with distinct augen structure. This belt is sandwiched between gneissic granite which grades on both flanks into normal granite. The granite of the western part of the area is a white variety which differs to some extent in appearance and mineral composition from the grey granite of the eastern part of the area, but in spite of these differences they are apparently parts of the same igneous mass. The succession of acid rocks in an east-west section is therefore as follows:—Grey granite, gneissic granite, banded gneiss, gneissic granite, white granite.

The basic rocks of the area consist of epidiorite dykes which invade the granite and gneiss. Many of these dykes have a rough north-south trend, but this is not universal. They are all small dyke bodies, rarely

more than a chain or two in width, and some may be followed along their strikes for a mile or more whilst others can only be traced for a few chains. In the south-east quadrant of the area epidiorite dykes are particularly numerous and most of them are persistent over long distances, whereas in the north-east quadrant they are rare, those that do outcrop being very narrow and usually non-persistent. Most of the dykes are massive, but in the gneissic parts of the area, some are sheared.

Granite.

The composition of the granite, indicated by numerous micrometric analyses, is as follows:—Quartz, 20–40 per cent.; felspar, 40–70 per cent.; biotite, 4–10 per cent.; muscovite, nil–4 per cent; epidote, nil–4 per cent. The altered state of much of the felspar renders impossible an accurate estimate of the quantity of each variety present.

The main differences between the white granite of the western portion, and the grey granite of the eastern portion of the area are set forth in the following table:—

	GROUP I.—White Granite—Western.	GROUP II.—Grey Granite—Eastern.
Macroscopic ...	Felspar, quartz, and muscovite form a white background for evenly distributed green-black biotite.	Felspar and quartz are not contrasted in colour against the green mica owing to the greyish and greenish tinges of the weathered felspar.
Microscopic ...	Appreciable quantities of primary muscovite, epidote, and biotite (Percentages are: biotite, 5–10 per cent.; muscovite tr.-4 per cent.; epidote, tr.-4 per cent.).	Small quantities of primary muscovite, epidote, and biotite (Percentages are: biotite 4–5 per cent.; muscovite, nil-trace; epidote, nil-trace).
	Ilmenite and leucoxene absent	Ilmenite and leucoxene present.
	Weathering less pronounced than in Group II.	Weathering more pronounced than in Group I.

Group I.—White Granite.

Type Specimen—6613.*

This specimen, which is characteristic of the group, is a holo-crystalline medium-grained rock containing quartz, felspar, biotite and muscovite. The quartz is generally water-clear while the felspar is white to cream in colour and slightly kaolinised in places. Green to black biotite occurs as small books or flakes evenly distributed throughout the rock. Silvery muscovite flakes are less abundant. The average sizes of the components are quartz, 2 mm.; felspar, 3 to 4 mm.; biotite, 2 mm.; and muscovite, 1–2 mm. in diameter.

The texture observed under the microscope is granitic, the mineral outlines being allotriomorphic. The felspars are represented by orthoclase and oligoclase, both of which show the same degree of alteration, and fresh interstitial microcline and injection micropegmatite. Quartz commonly

* Specimen numbers refer to the collection of the Department of Geology, University of W.A.

occurs as large allotriomorphs, which contain numerous inclusions of biotite, epidote, apatite, plagioclase and microcline, in addition to the usual gas and liquid inclusions. Some quartz individuals are traversed by irregular cracks, whilst most of them exhibit wavy extinction under crossed nicols, thus indicating a strained condition. Biotite, which is a strongly pleochroic brown variety, contains innumerable inclusions of epidote, apatite and sphene, and occasional inclusions of zircon. Muscovite is frequently intergrown with the biotite, but is less abundant. It contains just as many inclusions and some of these are very large, while some have intense pleochroic haloes. Both micas are deformed by pressure. Usually the deformation is characterised by simple monoclinal folds, but very contorted lamellae are sometimes seen. Epidote is a common primary mineral occurring frequently as definite crystals usually associated with muscovite and biotite. It is generally pale green to colourless and is feebly or non-pleochroic. Apatite, sphene, magnetite and zircon are the accessories and they are often found as inclusions in biotite and muscovite. Sphene also occurs as independent grains.

Grovp II.—Grey Granite.

Type Specimen—8093.

The texture of the grey granite is somewhat similar to that of the white granite, but the minerals are less clearly defined owing to weathering. The felspar is white, grey or faintly green tinged, and has a waxy or a pearly lustre depending probably upon the variety. The quartz is glassy or dull and does not stand out clearly against the felspar. Biotite is distributed throughout the rock as fine scaly aggregates. This form of the biotite, combined with the alteration of the felspar, is responsible for the grey colour of the rock.

In the thin section the identity of the plagioclase is almost concealed by its intense alteration to cloudy aggregates of granular epidote and zoisite. The potash varieties, on the other hand, are extremely fresh, but as they contain numerous shreds of quartz, they should strictly be called injection micropegmatites. Apart from this micropegmatitic intergrowth, orthoclase and microcline are rare. The micas are represented by biotite and a small amount of muscovite. Most of the former is altered to green chlorite, but a few unaltered patches remain. Several biotite flakes contain sagenite webbings in which the needles (probably rutile) are arranged in three directions at 120° to each other. The most characteristic inclusions in biotite are minute zircon crystals with pleochroic haloes, and an occasional large crystal of apatite. Of the epidote present, some is undoubtedly primary, but most of it is granular and is of secondary origin. Accessory minerals are poorly represented by ilmenite (with leucoxene) and zircon, whilst apatite is rare, and primary sphene absent.

The grey granite invariably shows some degree of granulation, and this feature is displayed by a variety of granite which shares the characteristics of the white and the grey granite. In thin section the type rock (8125) of this intermediate variety exhibits intense alteration and slight granulation. Quartz occurs as large allotriomorphs with strain shadows, containing inclusions of biotite and occasionally a little epidote associated with it. The greater portion of the felspar is obscured by kaolinisation and micacisation of the orthoclase and epidotisation of the plagioclase. Contorted lamellae of biotite and muscovite are common and although both are fairly

fresh, the biotite sometimes shows a peripheral alteration to finely divided chlorite scales. Zircon with pleochroic haloes, apatite and epidote are often found as inclusions in biotite, and these accessories, together with sphene, are abundant in muscovite.

A mineral which appears to be allanite is common in the type rock (8125), but it has not been observed in any other rocks of the granite groups, The mineral is light brown in colour, non-pleochroic and nearly isotropic, and it is always found enclosed by epidote. It usually occurs as rounded grains, but one individual noted was idiomorphic and crystallographically related to the epidote (Plate III., fig. 1).

Allanite exhibiting anomalous optical phenomena similar to those outlined above, has been described by several writers (Winchell, 1909, p. 186 ; Flett, 1898, p. 388 ; Mennell, 1903, pp. 345–347).

Gneiss.

Banded Gneiss.

Type Specimen 8145.—Gneissic banding is perfectly developed, and each band differs in the proportion of its minerals from the adjacent ones. The bands are of two types : large, varying from 10 to 24 mm. or more in thickness, and small, varying from mere stringers up to definite bands 5mm. in thickness. Of the large bands, some are apparently portions of slightly gneissic granite ; some are very felspathic, with little quartz and practically no biotite, and others are biotitic. The small bands consist of more or less alternating strings of biotite and felspar, the stringers of the latter varying in thickness because of lenticular swellings or eyes of felspar.

Three sections were made of the type specimen, one of the biotitic portion, another at right angles to the banding and the third of the felspathic portion.

(*a*) *Biotitic portion, containing extremely narrow bands of biotitic material.*

In section it is seen that there is not as much biotite present as indicated by the hand specimen. Quartz is the principal mineral present and it forms a heavily granulated "ground mass" for the surviving strained orthoclase plates and biotite stringers. Fresh microcline occurs as large ragged crystals with peripheral granulation. It exhibits the usual cross-hatching under crossed nicols, and in the same crystal may pass into normal untwinned orthoclase. Inclusions of plagioclase, quartz and biotite are common. Orthoclase is slightly turbid, but shows excellent cleavages. One large fragment contains inclusions of quartz and microcline, the latter forming an intergrowth, and also small plagioclase and apatite crystals. Micropegmatite and plagioclase are sparingly present. All the felspars exhibit strain shadows. The biotite is very stringy and is often altered to ragged aggregates of finely divided chlorite. Inclusions of apatite, zircon and sphene can sometimes be seen, and minute laths of muscovite when found are always associated with the biotite.

(*b*) *Section cut at right angles to the banding.*

The forms of the potash felspars and their intergrowths present in this section are :—

(i.) Microcline.
(ii.) Orthoclase.
(iii.) Orthoclase inverting to microcline.
(iv.) Perthite (orthoclase and microcline).
(v.) Injection micropegmatite.
(vi.) Graphic micropegmatite.

Most of these forms are too well known to warrant description, but several of them, as far as we know, have not yet been described in Western Australian rocks. Alling (1923) states that "the inversion of orthoclase to microcline . . . . involves a change in volume, and this introduces stress into the system" (p. 357). The straining of the orthoclase in this inversion to microcline is characterised by phantom twinning, but from Alling's microphotographs (plate I., p. 292) it seems obvious that the twinning referred to is a strain effect similar to that shown in the accompanying microphotograph of an orthoclase individual in the type rock (Plate III., fig. 2).

Injection microperthite (or micropegmatite) has been described by Colony (1923). "Frequently the end-phase products, quartz and albite, penetrate the earlier felspars, converting earlier orthoclase into a sort of 'injection perthite.'" This form has been noticed in the grey granite, but never in abundance. In the banded gneiss it is quite common. The quartz stringers or lenticles are arranged en échelon and the angle between their direction and the cleavage is always 107° or 108° (Plate III., fig. 3).

True micropegmatite of the graphic type is very common and resembles the diagrams of Iddings (1911, p. 239) and Luquer (1925, p. 99).

The biotite occurs as stringers frequently shattered into innumerable scales, some of which are partly chloritic. Sphene and apatite are abundant as inclusions, but epidote and zircon are rare. As in the previous section (8145a) the quartz is heavily granulated and muscovite is rare. About five irregular veins of calcite traverse the rock.

(c) *Felspathic Portion.*

No biotite is present in this section and with the exception of a few large grains of epidote and occasional patches of plagioclase, the rock is composed of potash felspars (and their intergrowths) and quartz. All the quartz is heavily granulated and all the felspars have wavy extinction. Some of the felspars have also undergone granulation, appearing as a delicate network with the spaces filled with granulated quartz. From the extinction measured from cleavage traces shown by occasional patches, the granulated felspar is orthoclase.

It is doubtful whether the epidote is primary or secondary. One patch in skeleton form is enclosed by allotriomorphic, apparently recrystallised, quartz.

Granite Gneiss.

Type Specimen—8106.

The texture noted in the hand-specimen is slightly gneissic, and is more evident on weathered surfaces than on the freshly broken surfaces. A pseudo-porphyritic texture is due to large pearly eyes of felspar in a dark grey biotitic "groundmass."

In section, the felspar intergrowths which characterise the banded gneiss, are seen to be very subordinate in the gneissic granite, but the delicate network or granulated "ground-mass" noted in 8145c is very common. Biotite and epidote are present in about equal quantities. The former varies in colour from brown to green, depending on the degree of alteration, and occurs as stringers or ragged patches associated with secondary muscovite, epidote and chlorite. A few fairly large flakes contain inclusions of apatite, sphene, zircon and epidote. Some of the epidote is primary, but most of it is secondary. A little primary muscovite is sometimes found in optical continuity with biotite. Plagioclase, though common, is usually very altered.

Relationship of the Gneiss to the Granite.

The main variables upon which the distinction of the types of granite and gneiss depends, are :—

(i.) The amounts of muscovite, biotite and epidote.
(ii.) The amount of micropegmatite (and other intergrowths):
(iii.) The degrees of granulation and gneissosity.

(i.) Muscovite, biotite and epidote are abundant constituents of the white granite and the intermediate variety. Wherever found these minerals occur in fairly definite proportions, so forming a mineral group in which muscovite and epidote are present in about equal quantities whilst biotite is equal in amount to both of these minerals.

In the gneisses these minerals are not very abundant although nearly always present. The grey granite contains less biotite than the white granite, and very little muscovite and epidote. There seems, therefore, to be a *gradual* decrease in these constituents from the white granite through the gneisses to the grey granite.

(ii.) Injection micropegmatite is rare in the white granite, abundant in the gneissic granite and extremely abundant in the banded gneiss. In the grey granite it is sometimes abundant (as in the type specimen), sometimes rare, depending to some extent on the degree of granulation.

(iii.) Granulation is related to gneissosity. The banded gneiss is more heavily granulated than the gneissic granite and is apparently more dynamically affected than the latter.

The field and petrographic relationship of the gneiss to the granite suggests that the gneiss is a phase of the granite, belonging to the same period of intrusion.

A possible explanation of the origin of the gneiss is as follows :—

A granitic magma invaded the area and commenced to crystallise on its margins, so forming the Eastern and Western belts. At the time of intrusion a period of diastrophism was beginning, and while the diastrophism was not severe the margins were able to crystallise as normal granite. With intense diastrophism the centre portion, which had not yet solidified, was forced to crystallise as gneiss.

In both gneisses, quartz was the last mineral to crystallise, and, owing to the accompanying pressure, some of it was squeezed into the earlier formed felspars, so forming the injection micropegmatite. The banded gneiss, which was subjected to very great pressure, contains more micropegmatite than the granite gneiss, which suffered considerably less pressure.

The granulation was subsequently imposed, and is believed to be due to another diastrophism accompanying, or subsequent to, the intrusion of the epidiorite dykes, for some of these dykes, where intruding gneissic belts, are sheared. The primary gneiss was granulated by this diastrophism according to the degree of its gneissosity, the banded gneiss being more granulated than the gneissic granite.

Epidiorite.

The term epidiorite was applied by Gumbel in 1874 to "diabases affected by regional metamorphism." Teall (1885, p. 198) describes rocks of the epidiorite type occurring in the highlands of Scotland. "The hornblende may be fibrous, actinolitic or compact. It often occurs as extremely ragged plates containing detached granules of a water clear mineral having the refraction and double refraction of quartz. The forms of the original

pyroxene grains are for the most part lost, so that replacement of pyroxene by hornblende cannot be strictly described as a case of either pseudomorphism or paramorphism. The modification of the pyroxene is accompanied by a modification of the felspar. In the epidiorite this mineral usually occurs as aggregates of irregular water clear grains in which needles and grains of hornblende occur as inclusions . . . . . . The outlines of the felspar areas in the epidiorite do not correspond with those of the felspar areas in the original rock."

The Upper Swan epidiorites present some variety in texture and composition. Some of them appear to be identical with Teall's epidiorites, whilst others are quite different. The hand specimens show considerable variation from fine to coarse grained epidiorite. Some are very felspathic ; others are very hornblendic ; but when examined under the microscope they are seen to vary between two extremes of texture, each of which is characterised by its own association of minerals. The members of Group I. are found in western portions of the area, and those of Group II. are confined to eastern portions.

Group I. (Western.)	Group II. (Eastern).
Texture intergranular. Hornblende laths and tablets embedded in a quartz felspar mosaic.	Texture usually obscured by alteration. Where definitely seen it is ophitic. Plates and tablets of hornblende enclosing felspar laths.
Hornblende is a strongly pleochroic blue-green variety usually containing abundant quartz inclusions. Occurs usually as laths.	Hornblende is a dirty green-brown variety, feebly pleochroic. Occurs usually as dense mats or large plates.
Felspar is usually granular and is untwinned.	Felspar when not zoisitised or obscured by alteration products is in large plates or laths, always twinned.
Magnetite and sphene present.	Ilmenite and leucoxene present.
Apatite rare.	Apatite common.
Quartz common.	Quartz not common.

Group I.

Blue green hornblende laths and tablets embedded in a quartz felspar mosaic. Quartz is common ; sphene usually present ; apatite is rare.

Type specimen—8085.

This is a very coarse, even-grained rock with a gabbroid texture, composed of an aggregate of green-black hornblende and pale pink felspar, the latter very subordinate in amount to the hornblende. Small white veins (·5mm. in thickness) traverse the rock.

Under the microscope, the hornblende appears in a variety of forms ranging from small laths or needles up to large irregular plates, all of which are embedded in an allotriomorphic aggregate of quartz and felspar. The hornblende is a strongly pleochroic variety, the pleochroism ranging from

light yellow-green to dark blue-green. Its inclusions are numerous, and, together with the hornblende they produce a poikilitic texture on a small scale (Plate III., fig. 4) in parts of the section.

The most common inclusion is quartz, which appears as small shapeless grains embedded in the hornblende plates, and from the detached nature of minute grains and needles of hornblende embedded in quartz it is evident that the quartz crystallised later than the hornblende and some of it was squeezed into already formed crystals of hornblende. Magnetite and sphene are other inclusions, and they are always much larger than the quartz grains and are always closely associated with each other.

The felspathic portion of the rock consists of allotriomorphic grains of untwinned felspar and quartz enclosing grains of epidote, aggregates or strings of granular zoisite, needles, grains and small laths of hornblende. In addition to these minerals the felspar is coated with extremely minute grains or scales which cannot be identified. The epidote minerals often form minute skeletal networks with the interstices filled with quartz. A vein of zoisite traverses the rock, cutting through several large plates of hornblende.

Group II.

Ophitic texture characterises this group. Some members, however, do not show the ophitic texture very well due to the breaking up of the hornblende into innumerable grains and small laths, which are now embedded in the felspar.

Type specimen—8097.

This is a dark grey coarse-grained rock consisting of a compact aggregate of green-black hornblende crystals and dirty felspars which do not stand out well.

The microtexture is typically ophitic. Hornblende tablets adjoin or penetrate each other to form a large mat enclosing huge laths and plates of felspar.

The hornblende is a pale green feebly pleochroic uralitic variety which has been partly chloritised, for large plates which appear homogeneous in plane polarised light, present a flecked appearance under crossed nicols, the interference colours ranging from 1st to 2nd order. This is evidently due to heterogeneity in composition. Magnetite dust is often peppered through the hornblende. The felspar is a smoky brown colour, is perfectly fresh and shows remarkably good twinning. Inclusions in the felspar are abundant, and they consist mainly of pale blue hornblende needles and grains of zoisite. They are not, however, evenly distributed throughout the felspar, but are mostly confined to the boundaries of the laths which penetrate each other, or to cracks traversing the felspars. There are thus portions of the laths which are perfectly free from inclusions and which appear remarkably fresh, quite unlike the evenly distributed zoisite grains in saussuritised felspar.

Any small interstices left between felspar and hornblende plates are filled with quartz. Wherever felspar is seen in contact with hornblende, the latter has been changed to the deep blue strongly pleochroic variety characteristic of group I. This variety fringes the felspar-hornblende contact and is evidently a reaction rim. The feature of this rim is that it does not grade into the uralite but ends abruptly.

Ilmenite and leucoxene are not very abundant in this rock, but there are several skeletal patches of magnetite with biotite filling the interstices. These skeletons are always surrounded by uralite. Quartz and apatite are not abundant, but in two other rocks of this group, 8141 and 8100, apatite, ilmenite and leucoxene are all fairly common.

Relationship between the two Epidiorite Groups.

The two epidiorite groups represent the two extremes between which all epidiorites in the area vary. There must consequently be intermediate types which cannot be definitely placed in one or the other group. Most of these intermediate types, including sheared epidiorite, are found occupying a broad north-south belt in the centre, whereas the epidiorites which can definitely be grouped are found in the extreme eastern and western portions of the area.

The field distribution and petrographic characteristics of the granite and gneiss are therefore paralleled by the field distribution and petrographic characteristics of the epidiorite. Both rock groups are more acid in the western than in the eastern parts of the area and both have an intermediate zone, in which the Swan River now flows, where banded gneiss has taken the place of the granite, and sheared epidiorite that of the massive epidiorite.

Origin of the Epidiorite.

Gumbel defined the epidiorites in general, as metamorphic rocks, but in the Darling "Range" (the Upper Swan area in particular) it is difficult to see how the epidiorites can be of metamorphic origin, for both the epidiorites and the granite into which they are intruded are, as a rule, quite massive and show no metamorphic effects.

The analyses of epidiorites from the Darlington Area (Clarke & Williams, 1926, p. 173) show that they belong to the plateau-basalt type of magma and that normally they should have crystallised as dolerites. The Upper Swan epidiorites do not differ to any marked extent petrologically from those of the Darlington Area and, therefore, may be assumed to have a very similar chemical composition.

Bowen has shown that any igneous rock may be formed from one magma depending upon the stage at which crystallisation-differentiation was arrested. For example, further differentiation of a rock about to crystallise as a gabbro may result in the formation of a diorite. But the rock would have the composition of a diorite, both mineral and chemical, whereas the epidiorites have the hornblende of the diorite, but the chemical composition of a basalt or gabbro. An extension of Bowen's theory by Colony (1923) would explain the origin of epidiorite. Colony supposes reaction will take place between the minerals already formed and the extreme end-stage products (gaseous and liquid) of the magma. This reaction is accomplished by the *squeezing* of the end stage products through the earlier formed minerals, converting them into minerals which normally crystallise at some later period. Thus augite would be converted into hornblende; the basic felspars to more acid varieties.

The pressure responsible for the squeezing effect is assumed to play a very important part in the conversion of dolerite to epidiorite.

Assuming the pressure to have been present (and judging from the gneissic belts, it undoubtedly was) it can be seen that the texture and composition of an epidiorite would depend upon the amount of end stage pro-

ducts present after the crystallisation of the original essential minerals. The small amount of quartz present in the less structurally altered members of Group II., and the large amount present in the completely altered members of Group I. seem to support Colony's theory.

Suggested Stages in the Magmatic History.

The granite invaded a series of old rocks which have now been entirely removed by erosion. Accompanying this intrusion was pressure in an E.–W. direction from which relief was got by the formation of a gneissic-zone. It is obvious that with the formation of a banded gneiss in the centre there would be transition zones of gneissic granite between the banded gneiss and the normal granite on both sides.

The granite belt nearer the Darling scarp contains an abundance of the flux minerals, biotite, epidote and muscovite, which are among the last minerals to crystallise in the magma, whereas the eastern granite belt shows a comparative rarity of these minerals. The inference is that the western belt is a more acid phase of the granite.

In the gneiss a banded structure was produced as a result of pressure, but as the magma was still partly fluid, the minerals arranged themselves along the direction of gneissosity without being granulated, and the later end stage products of quartz and felspar were injected by pressure into the earlier formed felspars, producing injection micropegmatites and microperthites. The gneiss so formed possessed a banded structure, but was not granulated.

At a later period, after the consolidation of the granite and gneiss, a basic magma squeezed its way along fissures which formed when the granite had cooled and contracted, and so the epidiorite dykes were formed. Those dykes found in the extreme west of the area are more structurally changed than those in the extreme east, but they are more acid than the eastern dykes in that they contain a larger amount of quartz.

The intrusion of epidiorite was followed by pressure which sheared many of the dykes, and which produced granulation in the banded and granite gneisses.

It is believed that both intrusions, granite and epidiorite, took place in the Pre-Cambrian era, but evidence for this cannot be found in the Upper Swan area. Since the epidiorite no igneous activity has occurred, but it is more than likely that movement has taken place along lines of weakness, and, if it is assumed that the Darling Peneplain has been separated from the Swan Coastal Plain by a fault, a subsidiary movement accompanying this fault may have been responsible for shearing of the epidiorite and the granulation of the gneiss, as well as influencing the present drainage of the Swan and Gatta rivers and their tributaries.

Fragmental Rocks.

In a previous section of this paper, the nature and distribution of these have been described and sufficient has been said of the alluvium. The other fragmental rocks—the duricrust and the ferruginous sandstone are more fully described in this section.

The Duricrust.—As far as one can see from hand specimens the duricrust of different levels is similar. It is quite similar to the material occurring elsewhere along the Darling Scarp. Rounded quartz pebbles, similar to

those of the alluvium, occur in duricrust close to the west boundary of the area at about 300 foot level. Low level duricrust (laterite) has been described from elsewhere in W.A. (Simpson, E.S. 1912, p. 399) as having been transported from higher levels. It is difficult to imagine that the duricrust of the saddle, despite the presence of the rounded pebbles, has been transported. It occurs in huge boulders which would surely have been broken up in transport. Thus the duricrust must have been formed at some time after the formation of the quartz pebbles and was formed in situ.

The Ferruginous Sandstone.—This consists of small rounded quartz pebbles in a ferruginous matrix. It occurs always associated with the duricrust, and at one place as one goes up a slope one passes over alluvium, ferruginous sandstone and finally on to duricrust. Whether the ferruginous sandstone forms a continuous band under the duricrust cannot be decided, but it seems reasonable to suppose that the iron of both the sandstone and the duricrust was derived from the same source and at about the same time. The rounded quartz pebbles are perhaps of similar age to the larger pebbles found distributed over a great portion of the area. Ferruginous sandstone has been found associated with duricrust at Bolgart and at Collie.

Associated with duricrust and sandstone in the saddle on the west of the area is a conglomerate consisting of rounded quartz pebbles and ferruginous pebbles about ½in. in diameter in a siliceous matrix.

IV.—RELATION OF THE TOPOGRAPHY TO THE GEOLOGY.

It has already been noted that the Swan Valley follows a zone of shearing. Creek G also flows in a zone of sheared rock. Shear zones are found also in the upper portion of Spring Creek valley, and the valley of Creek D, but these streams do not flow in areas of sheared rock throughout their entire length. Most of the spurs are found to have a "backbone" of epidiorite. It should also be remembered that duricrust and alluvium are confined to areas of more or less definite heights above sea level, but it is not necessary to enlarge on this because the occurrences of duricrust and alluvium have been dealt with in Section III. of this paper.

V.—SUMMARY.

The Upper Swan Area represents portion of a well dissected peneplain, with the surviving remnants of this old land surface approximating to a height of about 800 feet above sea level. The dissection has been accomplished by the south flowing Swan River wending its way at a low gradient to the coastal plain (which is about 70 feet below the level of the Swan where it leaves the area), the Gatta or Wooroloo Brook which flowing west meets the Swan at about the centre of the area and the numerous tributaries of these two main watercourses.

At high and low levels the igneous rocks are capped by duricrust and ferruginous sandstone, whilst in one place below the 300 foot form line, a conglomerate is associated with the duricrust and ferruginous sandstone. Alluvium occupies the present beds of the Swan and Gatta Rivers and some of their tributaries. It is also found at higher levels where it is characterised by the occurrence of rounded quartz pebbles. Where they outcrop the igneous rocks are seen to consist of granite and gneiss intruded by a net-

work of epidiorite dykes some of which are sheared in the gneissic parts of the area. The gneiss varies from slightly sheared granite, continuous with the main granite masses of the area, to a definite banded gneiss which outcrops prominently all along the valley of the Swan and also in several tributaries. It is believed that the granite and gneiss belong to one and the same period of intrusion, and that the gneissic structure is a primary feature, whilst the granulation is due to renewal of pressure in the area which occurred later than the intrusion of the epidiorite dykes. These dykes which are probably basaltic in chemical composition, should have crystallised as dolerites, but owing to the earlier formed minerals reacting with the volatile constituents of the magma mineralogical and textural changes were produced, resulting in the formation of epidiorite.

Both granite and epidiorite are more acid and less weathered in the western than the eastern portions of the area.

Since the intrusion of the epidiorite there has been no further igneous activity.

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GEOLOGICAL MAP OF THE UPPER SWAN AREA
LEGEND
Granite and Gneiss
Epidiorite
Alluvium
Strike of Shear Planes
Trig. Stations Δ P.V.
Geological Boundaries
Form Lines
LOCALITY PLAN
Spring
Spring
Spring
B.P.
SECTIONS ACROSS SWAN VALLEY
Scale
0 5 10 15 20 chains
400 800 1200 feet
Granite and Gneiss
Epidiorite

Plate I.


MODEL OF THE UPPER SWAN AREA
Granite and Gneiss
Epidiorite
Alluvium
Duricrust
Strike of Shear Planes
Photo. H. Smith
R.A.H.

Plate II.

Plate III.

Photo: H. Smith. x60.

MICROPHOTOGRAPHS OF SECTIONS OF ROCKS OF UPPER SWAN AREA.

Fig. 1.—Allanite in epidote. The Allanite (A) appears colourless in the photograph, but actually it is faint yellow in colour and nearly isotropic. 8125.

Fig. 2.—Orthoclase inverting to microcline. The extreme right of the crystal is normal orthoclase. 8145b. Under crossed nicols.

Fig. 3.—Injection micropegmatite in 8145b.

Fig. 4.—Inclusions in blue-green hornblende in spec. 6572, another member of Group 1.

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4.—WESTERN AUSTRALIAN ORTHOTETINAE.

BY LUCY F. V. HOSKING, B.A.

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INTRODUCTION.

Since the revision of the group Orthotetinae in 1908 by Dr. G. H. Girty* and later by Dr. I. Thomas** there has been no revision of the various members of this group recorded from Western Australia. The present note reviews the generic position of two previously recorded forms and describes a recently discovered specimen.

PREVIOUS RECORDS.

Fragments of shell have been recorded under the names "*Derbyia senilis*," "*Orthotetes*," or "*Orthothetes crenistria*," and "*Streptorhynchus crenistria*." References to all these records are given in "A List of Western Australian Fossils," G.S.W.A., Bull. 36, pp. 86 and 87, and "Supplement No. 1 to "A List of Western Australian Fossils," G.S.W.A., Bull. 88, p. 46, both papers by Mr. L. Glauert. Imperfect specimens in various collections are labelled apparently indiscriminately with any of the three generic names.

As far as can be ascertained no descriptions have been published of Western Australian specimens of *Orthotetes* or *Streptorhynchus* so that confirmation or otherwise of these generic names, in the light of their restricted meaning, cannot be made. One specimen, G.S., No. 10930, is figured by Etheridge, jun., as *O. crenistria*, G.S.W.A., Bull. 58, pl. I., fig. 10, but beyond the ornamentation this specimen shows no features on which it may be identified. It seems fairly certain that all records are based on fragments of shell showing the typical ornamentation of the group, and that the only more or less complete specimens of members of this group ever found are those from Mt. Marmion, described by R. Etheridge, junior (G.S.W.A., Bull. 58, p. 35, pl. VII., fig. 1 and 2), and a series from Luluigui Station, numbers 2772 and 2773 in the collection of the University of W.A., listed by Mr. F. Chapman in the Annual Report of the Geological Survey of W.A. for 1923, p. 36. Both

* U.S.G.S. Professional Paper 58, 156, 1908.
** Mem. Geol. Survey Great Britain Palaeontology, Vol. I., Pt. 2, p. 85 1910.

these series are reviewed below. Three unrecorded specimens are in the Museum collection labelled No. △ 57, *Orthotetes* cf. *O. semiplanus*, but as their locality "Gascoyne River, W.A." is not definitely known, their description is not included.

DESCRIPTION OF THE FOSSILS.

Genus DERBYIA Waagen (emend, Girty).

Salt Range Fossils Pal. Ind. Ser. XIII., Vol. IV., Fasc. 3, p. 591, 1884, and U.S.G.S. Prof. Paper 58, p. 181, 1908.

Derbyia cf. D. senilis Phil.

Pl. V., figs. 6 and 7.

1914, *Derbya* sp. Eth. Jun. G.S.W.A. Bulletin 58, p. 35, pl. VII., figs. 1 and 2.

Etheridge remarks on the uncertainty of the generic determination of these specimens from Mt. Marmion, but later examination proves them to be undoubtedly *Derbyia*. The original of Etheridge's Pl. VII., fig. 2, has the top of the ventral umbo worn down exposing the internal structure. A median septum is visible running from the pseudodeltidium to the floor of the ventral valve, but this has been crushed into an oblique position. There is a slight thickening on each side of the pseudodeltidium, but there are no dental plates forming the camerate structure of Orthotetes. The specimen is an unsatisfactory one to photograph, but pl. V., fig. 6, shows the umbonal region broken and the matrix which fills the shell crossed by an oblique septum.

The dorsal valve of this specimen and the dorsal valve figured by Etheridge on pl. VII., fig. 1, both show the socket plates as lines through the exfoliating shell. The impressions of the socket plates are shown better, pl. V., fig. 7, by another more worn specimen from the same series, not figured by Etheridge.

All the specimens are more or less exfoliated, but from their general shape, they approach closest to *D. senilis* Phil.* with which they agree in having the hinge line shorter than the greatest breadth of the shell, a high area, very convex brachial valve, and the shell crossed by irregular concentric step-like crumples.

Dr. Whitehouse, Aust. Assn. Adv. Science, 1926, p. 281 and 283. mentions the "so-called *Derbyia senilis*" from the Irwin River and from the Kimberley district and, using it in comparing beds on the East and West sides of the Continent, correlates the Western Australian "Permo-Carboniferous" with the Middle Bowen of Queensland.

* *Streptorhynchus crenistria* var. senilis, Dav. Mon. Brit. Carb. Brach. pl. XXVII., figs. 2, 3 and 4. *Derbyia* Waagen Salt Ra. Foss. Pal. Ind. Series XIII., Vol. IV., fasc. 3, p. 593.

The "*Derbyia senilis*" of the Bowen River** acording to Dr. Girty's interpretation of the figures† is a Streptorhynchus. According to Dr. Whitehouse it is a new species of *Orthotetes*.

As the only complete specimens from Western Australia are the Mt. Marmion specimens, which are certainly *Derbyia*, the "so-called *Derbyia senilis*" ceases to be of any value in comparing the faunas of the two regions.

Specimen Nos.—Amongst a group of Geological Survey specimens bearing the number 10930.

Genus STREPTORHYNCHUS King.

(Redefined by Girty, U.S.G.S. Prof. Paper 58, p. 164, 1908.)

Streptorhynchus luluigui, n. sp.

Pl. IV., fig. 1–7, Pl. V., figs. 1–4.

Schizophoria resupinata, Martin and *Productus cora* d'Orb	F. Chapman. List of Fossils from West Kimberley. Ann. Prog. Rept. G.S.W.A. for 1923, p. 36.
Do. do. do.	L. Glauert, G.S.W.A., Bull. 88, p. 46.

The specimens described below are placed in the genus *Streptorhynchus* on the following grounds:—

1. There is no median septum in the ventral valve seen in a section through the umbo (Specimen A), nor are there impressions of a median septum on any casts or partial casts of the ventral valve. (Specimens G, F and D).
2. Dental plates are absent (*see* Specimen A), but there is a thickening or ridge on each side of the delthyrium. These leave furrows on the cast, particularly marked near the hinge margin (*see* specimens E and F).
3. The dorsal valve has a well developed cardinal process (Specimen O) and strong socket plates curving round the muscular impressions (Specimens M, N and O).

They differ from the typical *Streptorhynchus* in showing little, if any, distortion of the umbo and area.

Numbers of separated valves, the ventral numbered 2773, and the dorsal, numbered 2772, were included in Mr. Chapman's list as *Schizophoria resupinata* and *Productus cora* respectively, and from this were incorporated in Mr. Glauert's supplementary list of West Australian Fossils in the column "Freney Oil Area."

A few better specimens now show the relationship of the two valves.

Description.—The united valves are biconvex or plano-convex. The ventral valve is ovate with a high umbo. The greatest width is about equal to or slightly exceeding the length. Longitudinally this valve is flat or very

** R. Eth. jun. Geol. and Pal. Qld., 1982, p. 246, pl. 12s, figs. 1–6.
† Girty, G. H., U.S.G.S., Prof. Paper 58, 1908, p. 169.

slightly convex. Transversely it may be almost flat to gently convex in the visceral region with gently sloping flanks. The convexity decreases towards the anterior margin where the valve is almost flat. Specimens which are almost flat in the visceral region, pl. IV., fig. 2b and 2c, pl. V., figs. 3 and 4, have a slightly longer hinge line and slightly wider umbonal angle than those which are convex in the visceral region, pl. IV., figs. 1b and 1c, pl. V., fig. 2 but the collection includes specimens intermediate between these two forms, *see* pl. IV., fig. 5, and ventral view of same specimen, pl. V., fig. 1.

The hinge line is much shorter than the greatest width of the shell. The area is high and about equally developed on either side of the pseudodeltidium, and inclined at an angle of between 120°–130° to the plane of junction of the two valves. In several specimens the area is flat, in others it is slightly concave (compare pl. IV., fig. 1c and 2c) and almost imperceptibly twisted to one side. It is marked with vertical striations on the less worn specimens. When the specimens are worn the horizontal growth lines on the area and pseudodeltidium become more pronounced and the vertical striations are lost. The pseudodeltidium is gently tapering and slightly convex and is flanked on each side by a narrow, almost parallel sided portion representing the inner or secondary area. In none of the specimens is this well enough preserved to show its ornamentation.

A plasticine impression taken from an internal cast, Specimen G, of the ventral valve, shows the muscle impressions faintly. The adductors lie close to the central line, are elongated, very narrow and nearly parallel sided. The divaricators are elongated, deltoid and extend beyond the adductors to about one-third of the length of the valve.

The absence of median septum and dental plates and the presence of thickened ridges at the edges of the pseudodeltidium have already been pointed out.

The dorsal valve is almost circular. Usually the convexity is pronounced and the shell swollen towards the umbonal region. Several specimens show a flattening of the top portion of the dorsal valve carrying on the slope of the ventral area, but this flattening is shown by the crumpling of the rest of the shell, to be due to pressure crushing the specimen. The umbo of the dorsal valve is inconspicuous. The area is absent or rudimentary. One specimen (J) shows a minute linear flattened portion, not 1 mm. wide, on each side of the cardinal process, but this does not extend more than 2/3rds of the total length of the hinge line. The cardinal process is large and strong and projects almost at right angles to the plane of junction of the two valves. Its external features are not at all well shown by the specimens. It is deeply divided in the central line. One specimen (J) shows only this two-fold division into two long narrow prongs. Another (K) less deeply imbedded in matrix, but much more worn, shows a wider process with a central and two lateral grooves giving a more or less quadriradiate arrangement. This apparent difference in the two specimens is, I think, only caused by the different amount of exfoliation shown by the two. The broader one seems to be worn down, exposing part of the socket plates. On the internal surface the process is broad. On a specimen, 47 mms. in length, it is 7 mm. wide and 7 mm. long. It is undivided for about 4 mm., then divides into two rounded prongs slightly diverging and each bearing a cup-like depression on its posterior end, pl. IV., fig. 4a. Below the cardinal process the socket plates are pronounced, forming a thickened process at each side at about the level of the hinge margin, thence extending as narrow, slightly raised, diverging ridges

on the interior of the shell for about a third of the length of the shell. The muscle impressions are separated by a faint ridge represented on the casts as a long shallow depression (*see* specimens I and O).

The valves are ornamented with very regular striae, which take an outward sweep on the lateral portions of the shell. The striae commence on the umbo as fine hair-like lines, but grow in size so that at the margin they are prominent ribs, about eight to twelve in the space of 5 mm. Additional fine striae are interpolated between the primary striae. These may or may not attain the same size as the primary striae, so that they can usually be distinguished on close examination, but the general impression is that the ribbing is even and regular particularly on the dorsal valve. On casts and very much ex-foliated specimens, however, the distinction between coarser and finer ribs is seen here and there. On casts the striae stand up as very sharp ridges separated by flat interspaces about twice the width of the striae themselves. There is no concentric ornamentation, but a few crumples more or less pronounced are seen on the lateral slopes of the ventral valve. On the larger specimens two or three well marked latilaminae are seen towards the margin (specimen H., pl. V., fig. 3). On one or two specimens the ribs have a faint beaded appearance due to the regular arrangement of rows of perforations down each side of each rib. (Specimen C.)

Dimensions.	3040, L.	$\frac{1}{5106}$B	Largest dorsal valve.	Largest ventral valve.
Length of ventral valve ...	41 mm.	...	...	51 mm.
Length of dorsal valve ...	34 mm.	...	45 mm.	...
Width	41 mm. (estimated)	...	58 mm.	abt. 52 mm.
Thickness of combined valves	19 mm.	11 mm.	...	...
Length of hinge line	24 mm.	25 mm.	...	...
Height of area	11 mm.	11 mm.	...	...
Width of pseudodeltidium at base	6–7 mm.	5 mm.	...	...

Remarks.—As noted in the description, a few of the characters seem rather variable in specimens in the present collection which comprises about fifteen specimens of each valve, but only two of the combined valves, *i.e.*, about thirty specimens in all. Further collecting may show that the forms included here under the one name may be separated into two groups—one represented by specimen L, pl. IV., fig. 1a–c, having a slightly shorter hinge line, more acute umbonal angle, slightly concave area and slightly broader deltidium, the other represented by specimen B, pl. IV., figs. 2a–d, having a longer hinge line, wider umbonal angle, flat area and narrower deltidium. There are a number of specimens in the collection intermediate between the two forms which, because of their imperfection, could not be allotted to one form rather than to the other.

S. luluigui differs from *S. pelargonatus* Schloth.* mainly in its greater size, the absence of marked median sinus, the absence of distortion of the area and absence of concentric growth lines. In external appearance *S. luluigui* is not unlike the Queensland specimens, figured and described by Etheridge as *Derbyia senilis*. Reference has already been made to the generic

* Davidson. Mon. Perm. Brach. (Pal. Soc. 1856). p. 32, pl. II., fig. 32–42.

position of these specimens. If they are *Streptorhynchus*, closer comparison with the Western Australian specimens will be necessary to state the specific differences.

O. perfidiabadensis,* a Northern Territory form, has a somewhat similar cardinal process, but differs in being a small shell with much less convex brachial valve.

Localities.—All specimens are from near the homestead at Luluigui Station (about lat. 18° 10′, long. 124° 1′) Kimberley division. Nos. 2772 and 2773 are labelled "highest horizon."

Specimen Nos.

$\frac{1}{5106}$ and $\frac{1}{5106}$ A, B and C.	Geological Survey.
2772 and 2772 M, N and O	Department of Geology, University.
2773 and 2773 E–H	
3040 and 3040 L	
3041 and 3041 I, J and K	

Streptorhynchus plicatilis, n. sp.

Pl. V., figs. 5a and b.

Description.—Shell longer than broad, almost flat longitudinally but slightly convex transversely. The umbo is very small, rather curiously shaped into a small peg-like structure projecting beyond the general surface of the valve. The hinge line is considerably shorter than greatest breadth of shell. The area is high, undistorted, with a broad, slightly elevated pseudodeltidium. Two strong teeth project from the cardinal margin and are produced for a short distance posteriorly on either side of the internal surface of the pseudodeltidium as low rounded ridges. The muscle scars are elongated, pear-shaped depressions extending about half the length of the shell and bounded anteriorly by irregular raised shelly ridges, one of which is considerably thickened, possibly due to injury. The shell is ornamented with broad radial ribs separated by hair-like furrows. Extra ribs are interpolated rather irregularly, sometimes two together. The ribs are crossed by innumerable fine raised lamellae, very close together, which can scarcely be seen with the unaided eye. There are a few concentric growth lines. These are scarcely noticeable on the earlier part of the shell, but become more numerous and marked towards the anterior. Here the ribs are grouped into irregular radial folds, from three to seven ribs in a fold.

Dimensions :

	mm.
Length	20
Maximum breadth....	20
Length of hinge line	13
Height of area	4
Umbonal angle—about 125°.	

* R. Etheridge, jun. Contrib. to Pal. of S. Aust. Suppl. to Parl. Paper, No. 55, of 1906, p. 6, pl. II., figs. 1–9, pl. V., figs. 3 and 4.

It is noteworthy that Etheridge compares this to *O. lens* White, which has since been made the type of the genus *Schuchertella*. Unfortunately the specimens cannot be found, according to a letter from Dr. Ward, who says, if they are in Adelaide, their whereabouts is unknown to him.

Remarks.—*S. plicatilis* is somewhat similar to *S. pectiniformis* Dav.* in general appearance, but differs in having less regular and less marked plications and much coarser radial striae. In shape, convexity, and dimensions, it agrees most closely with *S. lenticularis*† but differs from this in ornamentation. Judging by the illustrations *O. perfidiabadensis*,‡ Eth. jun., from the Northern Territory, may be compared with *S. plicatilis* in having fairly coarse ribbing, but it differs from *S. plicatilis* in having a more irregular ventral valve with a sinus.

Specimen No.—Geological Survey $\frac{1}{4972}$

Locality : Creek half mile West of Callytharra Spring, Wooramel River, W.A.

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* 1862 Dav. Quart. Journ. Geol. Soc. Vol. XVIII., p. 30, pl. I., fig. 17.
1884 Waagen Salt. Ra. Foss. (Pal. Ind.) I., iv., 3, p. 587, pl. LV., figs. 4–11.

† 1884 Waagen Salt. Ra. Foss .(Pal. Ind.) I., iv., 3, p. 581, pl. L, fig. 8.

‡ *See* previous note, p. 48.

LIST OF ILLUSTRATIONS.

PLATE IV.

All figures natural size.

Figs. 1a–c ... ... **Streptorhynchus luluigui,** n. sp., specimen 3040L, 1a, dorsal view, 1b ventral view, 1c side view.

Figs. 2a–d ... ... **Streptorhynchus luluigui,** n. sp. Specimen $\frac{1}{5106}$B, 2a dorsal view, dorsal valve fore-shortened by crushing, 2b ventral view, 2c side view, 2d looking down on area held in horizontal position to show true size and shape of area.

Fig. 3 ... ... **Streptorhynchus luluigui,** n. sp. Specimen 2772.0. Dorsal valve from which posterior portion of shell has been removed showing impressions of the dental lamellae, the matrix above the shell shows the imprint of part of the cardinal process.

Figs. 4a–b ... ... **Streptorhynchus luluigui,** n. sp., posterior portion of shell of specimen 2772.0. 4a seen from the internal surface showing the cardinal process and dental lamellae, 4b seen from the anterior showing the height of the dental lamellae and base of the cardinal process above the internal surface of the dorsal valve.

Fig. 5 ... ... **Streptorhynchus luluigui,** n. sp. Area of ventral valve 2773G, intermediate between the extreme types shown by specimens 3040L and $\frac{1}{5106}$B

Fig. 6 ... ... **Streptorhynchus luluigui,** n. sp. Specimen 2772N. Posterior portion of cast of dorsal valve showing impressions of the dental lamellae.

Fig. 7 ... ... **Streptorhynchus luluigui,** n. sp. Specimen I. Dorsal valve, shell removed from posterior portion showing slight median depression formed by low ridge between the two large rounded muscle impressions.

Owing to the difficulty of reproduction, figures 3 and 4a of Plate IV. do not show the outline of the cardinal process, so that it has been necessary to insert line drawings which are tracings from the original photographs.

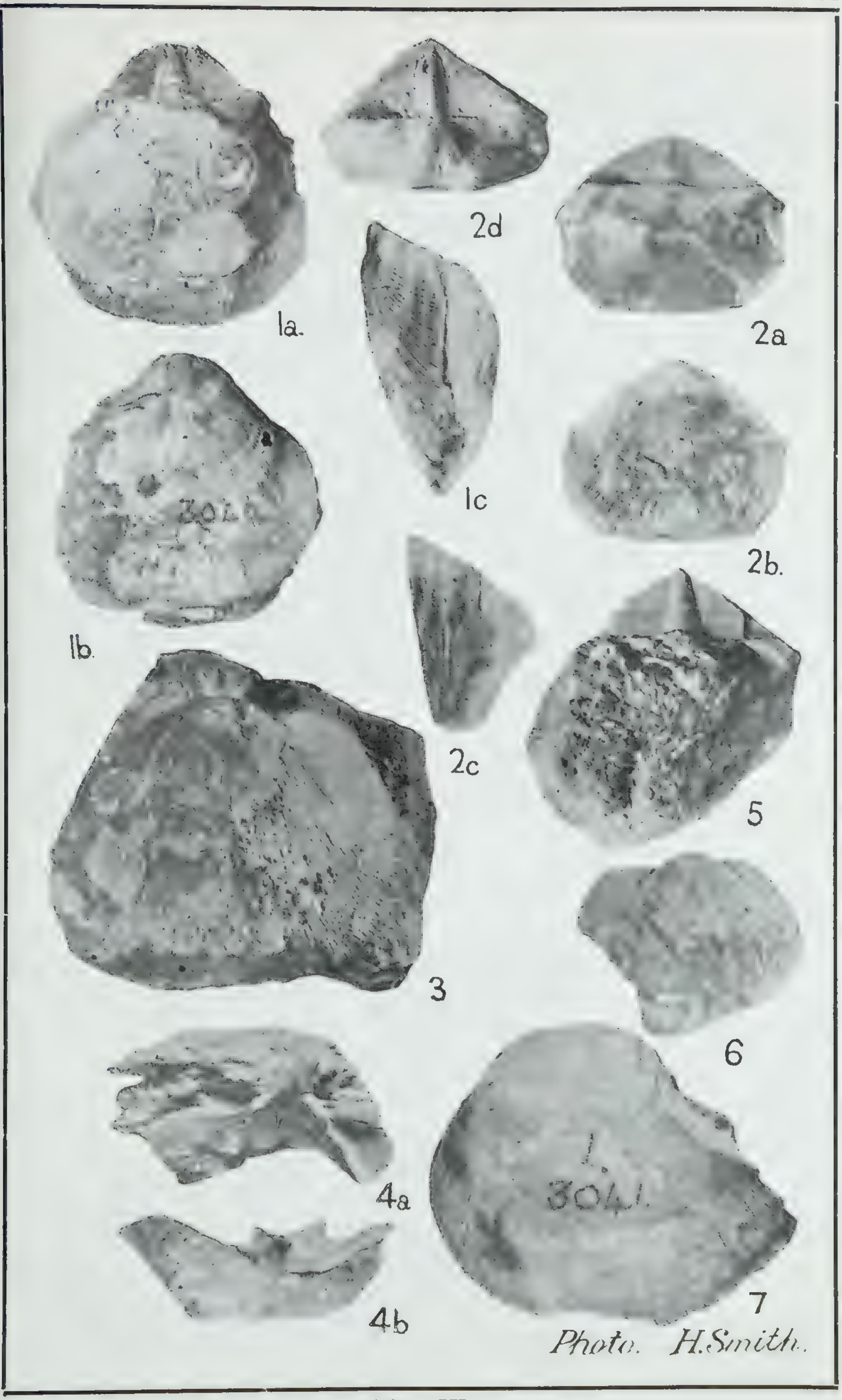

Plate IV.

PLATE V.

All figures natural size, unless otherwise stated.

Fig. 1 ... ... **Streptorhynchus luluigui**, n. sp. Cast of ventral valve 2773G, showing absence of median septum, faint elongated muscle impressions.

Fig. 2 ... ... **Streptorhynchus luluigui**, n. sp. Ventral valve slightly convex type.

Figs. 3 and 4 ... ... **Streptorhynchus luluigui**, n. sp. Ventral valves broader more flattened type. (Fig. 4 anterior margin of specimen broken away).

Figs. 5a and b ... **Streptorhynchus plicatilis**, n. sp.—
5a, ventral view $\frac{11}{10}$ natural size.
5b, ventral valve showing area, hinge and interior, natural size.

Fig. 6 ... ... *Derbyia* cf. *D. senilis*, Phil. Specimen figured in G.S.W.A. Bull. 58. Pl. VII., fig. 2. Ventral view showing median septum where umbo is worn away.

Fig. 7 ... ... *Derbyia* cf. *D. senilis*, Phil. Posterior view of exfoliated dorsal valve showing impressions of the socket plates.

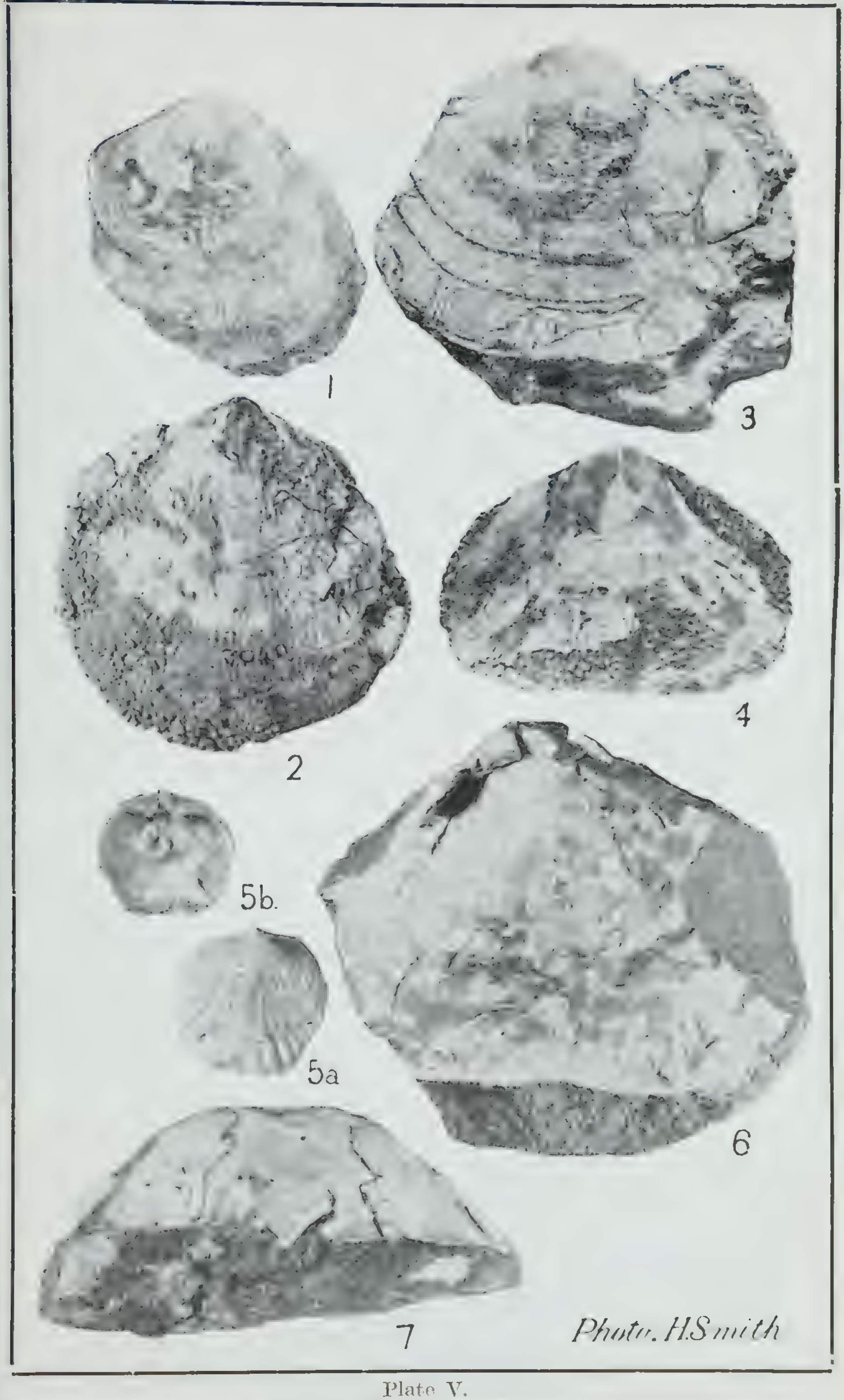

Plate V.

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JOURNAL OF THE ROYAL SOCIETY OF WESTERN AUSTRALIA,
Vol. XVIII., 1931-32.

5.—CHEMICAL INVESTIGATION OF THE EXTRACTIVES OF TWO WESTERN AUSTRALIAN WOODS.

By H. E. Hill, A.I.C., A.A.C.I.

(*Read November 10th*, 1931 ; *Published April 6th*, 1932.)

(1) THE OLEO-RESIN OF MYOPORUM SERRATUM.

Myoporum serratum (*N.O. Myoporineae*) is a species found growing on the Eastern Goldfields, where it is commonly known as "Dogwood." The tree attains a height of 20 feet and a diameter of 6 to 8 inches, and is said to be available in considerable quantities. The wood, even when green, burns with a bright flame, giving off a dense black smoke and characteristic odour. This and the rather pleasant sweetish aromatic odour of the wood indicate the presence of a considerable amount of oil. In 1930 a section of a log was forwarded to the Government Chemical Laboratory by the Conservator of Forests (Mr. S. L. Kessell) with a view to determining if it carried any essential oil or other extractive matter which might have some economic value.

The log consisted of 2½in. to 3in. of heartwood, which was brown in colour, surrounded by about 1¾in. of yellowish white sapwood. The heartwood possessed the strongest perfume. After de-barking the log was reduced to sawdust, which had a distinctly oily feel. On continuous extraction the comminuted wood yielded:—

to petroleum ether (B.P. 40-50°)	3.4%
to acetone	12.0%

In both cases the extract was a semi-fluid, sticky, red oil.

Steam distillation of about 1 kilogram of wood yielded 0.65% of a brown, sticky, resinous material.

Petroleum ether being the best solvent for the oils (acetone extracting much other extractive matter including resins) a considerable quantity of the comminuted wood (900 grms.) was exhausted by the former solvent, yielding 28.1 grams of a viscous dark red oil. This and the steam distillate were examined with the following results:—

	Petroleum ether extract.	Steam distillate.
Odour	Rather sickly aromatic odour, with occasionally a faint odour reminiscent of sandalwood.	
Refractive index n_D^{20}	1·5439	1·5165
Solubility in 90 per cent. alcohol ...	Sol. in 2 vols.	Sol. in 1 vol.
Saponification number	27	194
Acid value	4	59
Ester value	23	135
Saponification value of the acetylated oil	144	...
Unsaponifiable matter	81·4 per cent.	42·1 per cent.

A small quantity of phenolic or acidic constituents (6.2%), as determined by extraction of an ethereal solution with 10% caustic soda solution, was found in the petroleum ether extract.

Distillation: The petroleum ether extract on distillation under reduced pressure (30 m.m.) yielded over 50% of a pale yellow oil, B.P. 200-220°C., which on exposure to air changed in colour to a bright green. This possessed the characterisic odour of the wood and its extract. Its reactions indicated it to be an unsaturated hydroxyl compound probably of an alcoholic nature. The residue after distillation was a hard, dark red resin.

Summary: The wood of *Myoporum serratum* was found to contain 3.4 per cent. of an oil or oleo-resin extractable by petroleum ether. Steam distillation yielded 0.65 per cent. of oleo-resin, and acetone extracted 12.0 per cent., which included a considerable quantity of resin.

The oleo-resin consists of a high boiling point oil together with a hard, brittle, dark red resin. The odoriferous principle of the wood appears to reside in the fraction boiling at 200°-220°C. (30 m.m.) and may be a terpene or sesquiterpene alcohol.

The oil or oleo resin may have some value as a fixative in perfumery, but at present no other economic use for it can be suggested.

(2) THE OIL AND COLOURING MATTER OF THE STEM OF ACACIA ACUMINATA.

Acacia acuminata is a tree attaining a height of 30 to 40 feet, but usually under 20 feet. It is indigenous to Western Australia, where it is widely distributed, especially in the drier areas east of the Darling Ranges. It is plentiful in parts of the wheat belt, where the durability of the wood and its resistance to the attacks of white ants have resulted in its extensive use for fencing posts. The timber is one of the hardest, heaviest and most ornamental of Australian woods.

The common name, "raspberry jam" or "jam" is derived from the odour of the wood, which is similar to that of *Rubus indaeus,* the common raspberry. The odorous principle persists for years in specimens of the wood, but is most evident in the freshly cut timber. The presence of essential oil in the wood is indicated by the phenomenon of "sweating" or exudation of oil which has been observed to take place, especially from the heartwood.

This investigation was commenced with the object of gaining some information on the essential oil and the nature of the odorous constituent of the wood. No published record appears of any work having been done on this subject. The Forests Products Laboratory in Perth some years ago commenced an investigation. Steam distillation was tried with, it is understood, not very satisfactory results, but the work was not proceeded with.

The results of the present investigations were disappointing in regard to yield, the lowness of which, with the facilities at present available, made the separation and isolation of the constituents of the oil impossible. It was felt, however, that the results, which give indications of the nature of the oil and the colouring matter of the wood, should be published, and that later, if the means and time become available, further detailed examination might be undertaken. The work was carried out on portion of a log kindly supplied by the Conservator of Forests (Mr. S. L. Kessell).

Microscopic examination of the wood of *A. acuminata* shows the heartwood to be plentifully scattered with pores. These are vessels or tracheae that have become closed and are in most cases filled with a dark red deposit which appears to be of an oleo-resinous nature. This also appears throughout the parenchymatous tissue.

Extraction of oil: The log consisted of about 5in. of heartwood which was brown in colour, surrounded by about 1in. of yellowish sapwood and ⅜in. of bark. It was de-barked and reduced to shreds in a pulveriser. Extraction with light petroleum ether (B.P. 30°-50° C.) was carried out at room temperature by percolation, this being considered less likely to decompose the constituents of the oil. The extract was evaporated at a temperature not exceeding 60deg. C., the last remains of the solvent being removed under reduced pressure. The odorous principles did not appear to be volatile with the solvent at the temperatures employed.

Properties of the extract: Petroleum ether extracted 0.34% of a sticky, bright red (carrotty) paste, having a typical sweetish woody odour with a secondary odour of raspberries. The latter was fugitive, and was more noticeable from traces of the extract than the more concentrated form. The extract burned with a bright smoky flame, giving off a resinous odour. It was

A portion of the disintegrated wood which had been kept in the laboratory for eight or nine months yielded practically no coloured extract to petroleum ether, but considerable reddish brown colour to acetone and to alcohol, indicating that the carotene had become changed. This was not surprising in view of the instability of carotene and the avidity with which it absorbs oxygen.

It is interesting to note that Schmid & Pietsch (Chem. Abs. 1931.25. 4276) found the yellow alcohol soluble colouring matter of the "common acacia" wood to be a flavone.

The fact that carotene is closely related chemically to ionone, the chief odorous constituent of several essential oils, may possibly have some bearing on the chemical nature of the essential oil of *A. acuminata.*

I wish to thank the Government Mineralogist and Analyst (Dr. E. S. Simpson) for permission to publish the results of this work.

By Authority: FRED. WM. SIMPSON, Government Printer, Perth.

soluble in sulphuric ether, benzene, chloroform, and acetone, giving a deep orange-yellow solution. It possessed the following characteristics:—Refractive index n_D^{50} 1.515; saponification number nil, slightly soluble in 90% alcohol.

Reactions of the extract: The material, of which only a few grams were available, reacted strongly with bromine and iodine, indicating the presence of unsaturated compounds. A characteristic and beautiful colour reaction was obtained when one or two drops of concentrated sulphuric acid were allowed to flow into the solution of a small quantity in acetic anhydride. The solution turned emerald green, rapidly changing to deep blue. A similar reaction is given by the sesquiterpene cadinene in chloroform solution, the blue changing to red on heating, however, which is not so with the material under question. The extract dissolved in concentrated sulphuric acid with a blue colour. Its solution in chloroform gave a blue colouration with antimony trichloride and with zinc chloride. The solution in absolute alcohol deposited on standing a small amount of what appeared to be a stearoptene or paraffin.

Nature of the oil: The reactions and properties of the extracted oil indicate that the principal constituents are of a terpene or sesquiterpene nature with probably a stearoptene present. The odorous principle, as is to be expected, has no chemical relation to that of the raspberry, which is chiefly composed of esters. The odorous constituents of the wood of *A. acuminata* are unchanged by extraction and persist in the unsaponifiable portion.

The resin: The acetone extract from the wood was found to be hard, brittle, dark red resin, soluble in alcohol, and having a saponification number of 255.

The presence of Carotene: The solution yielded by the wood to petroleum ether and other organic solvents had a bright orange-yellow colour. The concentrated extract possessed strong tinctorial power, and stained objects a bright yellow. The colouring matter, however, was not soluble in water or in aqueous solutions of acids or alkalis. Prolonged boiling with 6% hydrochloric acid solution yielded no hydrolysis products giving coloured solutions with acids or alkalis. It did not, therefore, belong to either the anthocyanin or anthoxanthin group of plant pigments, but appeared to be a carotinoid or lipochrome. Further examination showed the colouring matter to resemble carotene in the following respects:—solubilities, non-extractability with 80% alcohol from petroleum ether solutions, and rapid fading of solutions in bright sunlight. The visual absorption spectrum showed bands in the region of the two bands in the blue violet end of the spectrum given by carotene. Carotene and vitamin A, its derivative, both give the blue colour in chloroform solution with antimony trichloride and zinc chloride mentioned above, a reaction which is considered specific for them.

On standing, the pasty petroleum ether extract of the wood deposited numerous tiny tabular pleochroic crystals. These showed considerable resemblance to the intracellular specks of carotene seen in the root of the carrot and to carotene extracted therefrom. There is little doubt that a considerable portion of the colouring matter in the stem of *A. acuminata* consists of the pigment carotene. It appears to be dissolved in the oil held in the pores, and no microscopic crystals have been noted in the wood.

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6.—CONTRIBUTIONS TO THE MINERALOGY OF WESTERN AUSTRALIA—SERIES VII.

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(With four Figures.)

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(1) CHRYSOBERYL AND ASSOCIATED MINERALS, DOWERIN, S.W.

Chrysoberyl was discovered in 1930 on block DAA 41, first in a boulder in the soil of a wheat field, and later *in situ* at a shallow depth. The associated minerals, in order of abundance, are eastonite (green black), a brown black mica, cummingtonite, and actinolite, with smaller quantities of almandine, andesine, quartz, schorl, magnesite, calcite (travertine), and apatite.

Chrysoberyl. This occurs in a mixture of black mica (eastonite), almandine, andesine and quartz, forming a small pipe at most 60 cm. (2 ft.) square in section, apparently at the crossing of two small vertical pegmatite veins which are accompanied by much micacised rock. The rock mass disclosed in the workings to a depth of 3 metres (10ft.) is a cummingtonite-black mica gneiss with narrow bands of bright green actinolite. The chrysoberyl has been found embedded in all four of the minerals forming its immediate matrix, viz. eastonite, andesine, almandine and quartz, but is most plentiful in the mica, especially in the vicinity of almandine nodules, where as many as four or five crystals have been counted in an area 2 cm. square.

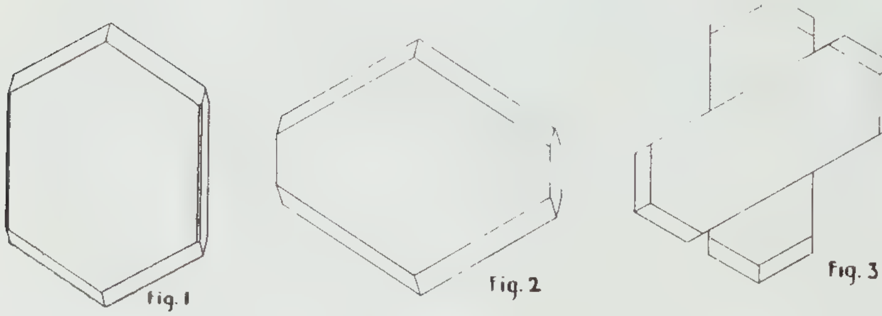
It appears in single scattered crystals, more or less perfectly developed, from 0.5 mm. in diameter up to the largest weighing 1.2 carats and measuring 10 x 4 x 2 mm. The crystals are usually tabular parallel to *a* (100), which face is not uncommonly vertically striated, and in one case shows an arrowhead striation due to repeated interpenetrating twinning on (031). The crystals are usually a combination of *a* (100), *b* (010) and *o* (111), Occasionally the edge *a b* is bevelled by the face *m* (110). Common forms are shown in Figs. 1 and 2. Fig. 3 represents a unique form of twin on

(031) in which two superimposed prisms are countersunk into one another to the extent of half their thickness. The angle measured under the microscope between the pyramid edges was 60°; theory requires 60° 26′ (Hintze), 60° 14′ (Dana). The specific gravity determined by Clerici solution on a number of crystals was 3·70 ± .02.

All the smaller crystals are perfectly transparent and flawless, but the largest ones are turbid with inclusions of mica, etc., and are imperfectly developed. The clear crystals found so far have all been too small to cut into gems. The commonest colour is "fluorite green" (R. 33″), but some are a darker green, others lighter, whilst a few are a greenish yellow (R. 23″ to 23″ b) and still fewer almost colourless. Very rarely a crystal is darker green in the centre than in the periphery. A few of the deeper green crystals become violet-purple in artificial light, the peculiar colour change characteristic of alexandrite, and due to chromium being the colouring agent. Under the microscope the crystals show a straight extinction, and the observed pleochroism is:—

—	Green Crystals.	Yellow Crystals.
X (a) ...	Pale greenish yellow, light green or rarely lilac ...	Pale yellow
Y (b) ...	Pale yellow or greenish yellow to colourless ...	Colourless
Z (c) ...	Emerald green to pale green	Greenish yellow

This is the first recorded occurrence of chrysoberyl in the State.



Figs. 1, 2, 3.—Chrysoberyl, Dowerin.

(1) Common type of crystal. Forms: *a* (100), *b* (010), *m* (110), *o* (111).

(2) Common type of crystal. Forms: *a*, *b*, *o*.

(3) Twin on (031). Forms: *a*, *b*, *o*.

Fig. 4.—Corundum crystal largely altered into Muscovite, with central core of unaltered Corundum. Forms· *r* (10–11), *z* (22–41).

Eastonite. A black mica is very abundant in one of the pegmatite veins, and in the gem bearing pipe. It is mostly bottle green (28′m. and lighter) in thin flakes, and almost uniaxial, 2 E being not more than 3°. Some flakes are dark brown (9′m. and lighter) with a slightly larger optic axial angle, 2 E about 5°; other flakes are between these two in colour. The brown are probably derived from the green by oxidation. Very few pleochroic haloes were observed. The mineral is in coarse grained masses, with flakes from 2 or 3 mm. to occasionally several centimetres in diameter.

An analysis was made of carefully selected material from the gem-bearing pipe. It was almost all of the green variety, but some flakes were olive or brown. The results are given in the table. The molecular ratio Mg : Fe + Mn is 62 : 38, placing the mica in the phlogopite-eastonite series of the biotite group. A comparison of the molecular ratios of the Dowerin mineral with those of the two type minerals shows:—

	(OH,F)	K_2O	MgO	Al_2O_3	SiO_2
Phlogopite ...	4	1	6	1	6
Dowerin Mica ...	5	1	5·5	2	6
Eastonite	4	1	5	2	5

The Dowerin green-black mica therefore lies almost midway between the two species, but in the relative proportion of alumina is obviously nearer to eastonite. There is evidence of slight hydration due to surface alteration.

No details are available regarding the brown-black mica which is the common one in the gneiss, but which, judging from the specimens collected, is of rare occurrence in the pegmatitic material. It is probable that it only differs from the green mica in possessing somewhat more Fe_2O_3 and less FeO. As already stated, it possesses a slightly greater optic axial angle.

MINERALS ASSOCIATED WITH CHRYSOBERYL, DOWERIN.

——	Eastonite.		Cummingtonite.		Actinolite.		Andesine.		Almandine.	
	%	mols.	%	mols.	%	mols.	%	mols.	%	mols.
SiO_2 ...	35·84	597	58·80	979	55·72	928	63·02	1049	37·23	620
Al_2O_3 ...	16·68	163	*Nil*	—	·78	8	23·26	228	21·13	207
Fe_2O_3 ...	4·14	26	trace	—	1·51	9	·10	—	trace	
FeO ...	14·69	204	13·07	182	6·72	94	·22	3	31·33	436
MnO ...	·33	5	·69	10	·60	9	trace	—	3·41	48
NiO ...	*Nil*	—	*Nil*	—	·07		*Nil*	—	*Nil*	—
MgO ...	13·87	344	24·69	613	21·88	543	·35	9	4·09	101
CaO ...	*Nil*	—	·64	11	10·28	183	6·74	120	2·08	37
Na_2O ...	·48	8	*Nil*		·14	2	6·38	103	*Nil*	—
K_2O ...	8·48	90	*Nil*	—	·16	2	·40	4	*Nil*	—
H_2O + ...	4·24	255	2·50	138	2·11	117	·14	—	trace	
H_2O — ...	·42	—	·02	—	·08	—	·07	—	*Nil*	—
Ti_2O_3 ...	·36	3	...	—	...	—	trace	—	...	—
F	·96	51	...	—	...	—	...	—	...	—
Total ...	100·49		100·41		100·05		100·68		99·27	
O = F_2 ...	·40									
Net total...	100·09									
G	3·00		3·06		3·05		2·67		4·18	
Analyst ...	D.G.M.		E.S.S.		D.G.M.		D.G.M.		H.P.R.	

Cummingtonite (Ferruginous Kupfferite). A coarsely crystallised, creamy-white, amphibole is absent from the pegmatite, but is the major constituent of the enclosing gneiss. The broader bands of this are composed of a mixture of cummingtonite and eastonite in the proportion of 2 or 3 to 1. Certain narrow bands, 0.5 to 1.0 cm. wide, consist practically wholly of this amphibole. The composition of material separated by methylene iodide between 3.05 and 3.10 is given in the table. It yields the formula $H_2(Mg,Fe)_7Si_8O_{24}$ with Mg : Fe + Mn = 76 : 24. This composition is

common to ferruginous kupfferite (cummingtonite), which is monoclinic, and ferruginous anthophyllite which is orthorhombic. Optical tests prove the Dowerin mineral to be monoclinic with an extinction angle $Z \wedge c = 15°$ and the acute bisectrix parallel to X in the plane (010). Ng and Np are respectively 1.639 and 1.618. Under the microscope it is colourless and transparent, with prismatic cleavages making an angle of approximately 60°, and frequently exhibiting twinning on (100), sometimes multiple. It is coarsely prismatic or tabular in habit with prisms usually up to 5 or 6 mm. in length and 2 or 3 mm. in width, but occasionally in the pure veins it is in much larger tablets reaching 20 by 10 mm.

Actinolite. Certain narrow bands in the gneiss are conspicuous because of their bright green colour. These prove to be composed almost entirely of a nickeliferous actinolite ranging in tint from "sage" (R 29^4) to "American" (33^3 i) and "pistachio" green (33^3). The masses are in long narrow bands and interbedded lenses from 1 to 20 mm. thick. The mineral is granular and glassy, the grains only loosely coherent. Under the microscope they are seen to be angular, 0.2 to 0.5 mm. in diameter, transparent and almost colourless to very pale yellowish-green. No typical structure is seen until the mineral is lightly crushed, when the prismatic cleavage yields tabular and prismatic granules. The basal plane shows up well in some of the latter, making an angle of 103° with the vertical axis. The mineral is monoclinic with a maximum extinction angle $Z \wedge c$ of 17°. The analysis given in the table yields figures approximating to the actinolite formula: $H_2Ca_2(Mg,Fe)_5Si_8O_{24}$.

The unusually bright green colour must be ascribed to the presence of nickel and ferrous iron together. It is worthy of note that the two monoclinic amphiboles, one lime-bearing, the other not, have crystallised separately in the rock, and not together to form a single species.

Andesine. Masses of a multiply-twinned felspar are rather common in the gem-bearing pipe and one of the micaceous pegmatite veins. They vary in colour from a dirty milk-white to glassy colourless, or with a faint tinge of grey or brown. Some of this glassy mineral is perfectly transparent in flakes several millimetres thick, and occurs in crystal individuals several centimetres in length and thickness, and usually showing under the microscope multiple twinning on (010) in very thin layers, with an extinction angle of 3° on a basal cleavage. The clearest mineral was analysed with the results shown in the table. These indicate a ratio of albite (plus microcline) to anorthite of 64 to 36, bringing the mineral within the subspecies andesine.

Almandine. This garnet is entirely confined to the gem-bearing pipe where it appears as large nodules, usually several centimetres in diameter and devoid of crystal faces. It sometimes encloses crystals of chrysoberyl. The garnet is translucent in layers of 0.5 to 3 mm. thick, and is of a brownish-red colour (R 1^1 i). An analysis is given in the table. The ratios of $RO : R_2O_3 : SiO_2$ are 623 : 207 : 620 which are extremely close to the theoretical ones of 3 : 1 : 3. The relative proportions of the different garnet molecules present are:

Almandine.	Spessartite.	Pyrope.	Grossularite.	Total.
70·0	7·7	16·3	6·0	100·0

This is the only iron magnesium silicate in the whole complex in which the iron preponderates over the magnesium.

Apatite. A mineral of rare occurrence in nodules and hexagonal prisms in the gem-bearing pipe has proved to be apatite. It is greyish-white, greenish-white, or faintly olive in colour, and varies greatly in translucency from completely transparent in a 3 mm. layer to faintly translucent in a 1 mm. layer. The specific gravity was found to be 3.20 and the mineral yielded the usual chemical reactions. Prisms ranged in size from 2 x 5 mm. to 7 x 15 mm. The smaller ones showed only *m* (10—10); larger one showed narrow faces also of *a* (11—20). The mineral is usually embedded in masses of eastonite.

Magnesite and Calcite. White porcelanous nodules of magnesite are scattered through the soil in the immediate vicinity of the chrysoberyl workings. In the open cut they are seen to arise from veins and strings of nodules in the weathered portion of the gneiss.

Jointed and dislocated fragments of the gneiss and pegmatite are often coated with a thin layer of travertine, the average rainfall (15 inches) and drainage in this district being insufficient to dissolve and carry away the whole of the less soluble products of rock weathering.

Quartz and Schorl. A small quartz-schorl pegmatite vein intersects a larger eastonite-andesine vein in the workings and the gem-bearing pipe appears to occur at their intersection.

Surroundings. The only outcrops appearing in the immediate vicinity are those of a large siliceous pegmatite and several dykes of different types of greenstone. It is probable that the cummingtonite-eastonite gneiss is a highly altered pyroxenite or hartzburgite. Granite is not far away in every direction.

(2) COLUMBITE AND TAPIOLITE, JIMPERDING, S.W.

The prospectors who have been obtaining a little alluvial and eluvial gold on a branch of Jimperding Brook have often obtained a small amount of heavy black gravel in their dish concentrates. Physical and chemical tests have proved much of this to be normal columbite.

The recognisable fragments of the mineral are from 3 to 10 mm. in length and tabular in habit. The heaviest piece was just under one gramme in weight. The faces, proved by measurements with a contact goniometer, are *a* (100), *b* (010), *c* (001), *u* (133); all of which are common. Only rarely are seen the faces *e* (021), *m* (110) and *z* (530). Groups are seen in which (1) all faces are parallel, (2) the (010) face is common to all subdivisions or parallel throughout, but the (100) faces differ in orientation by successive amounts of about 10°, giving a fan-shaped arrangement. The colour of the fragments is black with lustre sometimes dull, sometimes brilliant. The specific gravity of the largest crystal is 6.29, and that of ten small ones, averaging 0.1 gramme each, is 6.33.

An analysis of a small crystal gave the following results:—

COLUMBITE, JIMPERDING.

	Ta_2O_5	Nb_2O_5	FeO	MnO	Total.
Per cent. ...	44·5	38·0	13·5	4·0	100·0
Mols ...	101	142	188	56	

In one parcel of concentrate a single crystal of tapiolite (tetragonal $FeTa_2O_6$) was detected. It is 10 mm. long and weighs 0.95 gramme. The ends of the crystal are broken but the faces s^1 (111) s^2 s^3 s^4 are large and well preserved and a^1 (100) and a^3 (—100) small but distinct. Like many tapiolite crystals, this one is elongated parallel to the edge s^1 s^2. The measured angle between these two faces is 57° (calculated 57° 0′), and *a s* 61° 30′ (calculated 61° 25′). The specific gravity was found to be 7.75, which, taken in conjunction with the crystallographic data, leaves no doubt as to the identity of the mineral.

A much smaller crystal, only 3 mm. in length, is also probably tapiolite. No density determination could be made but s^1 s^2 measured 57°.

(3.) CORUNDUM, LOWER CHITTERING, S.W.

In prosecuting his intensive search of the Chittering Valley for unusual minerals and rocks Mr. J. E. Wells has made an important discovery near the southernmost extension of those Precambrian schists, which at various other points in the valley have yielded kyanite, sillimanite and staurolite in abundance.*

Between the Bullsbrook Road and the confluence of the Chittering with the Swan, in an area where he had previously found sillimanite, kyanite and pseudomorphs of muscovite after andalusite, he has now discovered corundum. The exact position is about 1½ miles east of C.G. 1260, near the summit of the range and on the south side of a gully which joins the main valley on that Crown Grant.

The corundum occurs only over a very small area, about 3 x 1 chains (60 x 20 metres) embedded in the outcrop of a narrow band of quartz-biotite schist flanked on either side by granite, which is succeeded in turn on the west by alternate bands of micacised andalusite schist and granite.

In this small outcrop corundum crystals have been quite common, until a later stage of intense metasomatism converted them into sericite, leaving however a core of unaltered corundum in the centre of many of the largest. Most of the individuals, which lie at all angles in the schist, are fairly well crystallised, and reach a maximum of 5 inches in length and one inch in diameter (13 x 2.5 cm.). The micacisation has not been sufficiently violent to destroy the outline which is that of a bipyramid *z* (2241) clearly terminated in some distances by the rhombohedron *r* (1011). Rough measurements gave:—

z^1z^4	21°	Theory	20°48′
z^1z^2	59°		58°55′
r^1r^2	94°		93°56′

Composite crystals, of which there are a few, do not appear to be twins, but rather adventitious intergrowths. A cross section exhibits a hexagonal surface of grey, micro-scaly, obscurely radiating mica, with or without a central core of unaltered corundum. This core in some crystals is small and has a ragged boundary firmly adherent to the mica. In other crystals it is larger and perfectly circular or oval in cross section, parting readily and cleanly

* *See* this volume, pp. 75–82.

from the mica. (See Fig. 4, page 62.) The mica and core from such a crystal were examined separately in detail. The mica proved to be a barium-bearing muscovite as the following figures show:—

MUSCOVITE PSEUDOMORPH AFTER CORUNDUM, LOWER CHITTERING.

SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	BaO	MgO	Na_2O	K_2O
44·28	35·64	2·56	*Nil*	·28	1·16	·28	·36	10·34

H_2O	F	TiO_2	Total	G.
4·92	n.d.	·14	99·96	2·86

Analyst—D. G. Murray.

The core is brownish or purplish in colour, with a dull to subvitreous lustre. It has a specific gravity of 3.90 and a hardness of over 8. No and Ne are both over 1·733. In most cases the rhombohedral twinning and parting are obvious, the measured angle between the faces being 94°. The powder is transparent, and for the most part colourless; some fragments, however, are more or less deep blue, or partly blue and partly colourless. Thin films of limonite penetrate the natural partings and cracks. A partial analysis of a small chip showed Al_2O_3 (with traces of Fe and Ti) 95.72 per cent; SiO_2 4.88 per cent.

This is the only corundum known west of Jacob's Well.

(4) DIOPSIDE, NEVORIA, CEN.

Basic pegmatites are not common in our Precambrian greenstones, so that the composition of one found at Nevoria is worth recording. On the dump of the Banker G.M. the writer found some large masses of amphibolite through which ran a pegmatite vein about a foot (30 cm.) in width. This was composed chiefly of large lamellar masses of a pyroxene, associated with smaller and finer grained masses of a dark green amphibole and occasional coarsely crystalline calcite.

The pyroxene proves to be a ferruginous diopside (salite), as the following analysis shows:—

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O
Per cent. ...	52·71	·98	1·28	5·77	·24	14·84	22·53	*Nil*
Mols. ...	877	10	8	80	3	368	402	—

	K_2O	H_2O+	H_2O-	TiO_2	CO_2	P_2O_5	Total.	G.
Per cent.	·08	·64	·22	·08	·18	*Nil*	99·55	3·26
Mols.	1	36	—	1	4	—		

These figures give the following molecular percentages:—

$CaMgSi_2O_6$	73
$Ca(Fe,Mn)Si_2O_6$	19
$Mg_2Si_2O_6$	4
$Mg(Al,Fe)_2SiO_6$	4
	100

The mineral is pale grey to grey green (near $R29^4b$) in colour, and not pleochroic. It is very coarsely crystallised, with marked basal parting. The maximum extinction angle which was measured was 31°. Under the microscope a slight alteration to amphibole and chlorite is noticeable round the boundaries and along the cleavages of the crystals.

(5) MARGARITE AND CORUNDUM, GIBRALTAR AND NEVORIA, CEN.

Margarite has not previously been detected in this State, though many years ago found at Woodside in South Australia, and Mt. Read in Tasmania. This year it has been found in two places about 100 miles apart, viz., Gibraltar and Nevoria. In each case it is intimately associated with corundum.

Gibraltar.—The margarite from 2 miles south of the Gibraltar G.M. is in irregular groups of large (2 to 5 mm.) scales embedded in microgranular grey corundum. These larger scales are often grouped in imperfect rosettes, and the flakes in other groups are never parallel over a large area. They are greyish-white in colour and slightly less transparent and more brittle than muscovite. In one case what appears to be an imperfect hexagonal prism of corundum 30 mm. in diameter is entirely surrounded by a layer of radiating scales of margarite. Besides the larger scales there are innumerable smaller scales down to microscopic size scattered through the corundum.

An analysis made of some of the coarser mineral separated by CH_2I_2 gave the following results:—

MARGARITE, GIBRALTAR.

	SiO_2	Ti_2O_3	Al_2O_3	Fe_2O_3	MnO	MgO	CaO
Per cent. ...	31·38	·10	48·98	1·55	·02	1·10	8·00
Mols.	522	1	481	10	—	27	143

	Na_2O	K_2O	H_2O+	H_2O-	Total.	G.
Per cent. ...	3·14	·18	5·71	·11	100·27	3·04
Mols.	51	2	318	6		

Such sodium-bearing margarites have been called Clingmanite, and are known from Madison, North Carolina; Unionville, Pennsylvania; Back Creek, South Island, New Zealand; Bynarka, Urals; Village Green, Pennsylvania; and Nicaria Island, Asia Minor. These carry respectively 6.15, 4.78, 4.74, 3.76, 2.97 and 2.86 per cent. of Na_2O. The soda-bearing molecule has not been worked out as yet. One would expect it to be the paragonite molecule $H_2NaAl_3Si_3O_{12}$, which differs only from the margarite molecule by the common substitution of NaSi for CaAl. This molecule does not, however, satisfy many of the analytical data.

Under the microscope the scales of the Gibraltar mineral are colourless and transparent, slightly birefringent, with the acute bisectrix almost perpendicular to the basal plane and a large optic axial angle in air. They are sometimes penetrated by small corundum crystals.

The 0.25 mm. concentrate of corundum from Gibraltar is pale grey in mass but colourless and transparent or translucent under the microscope. Among many angular fragments are a few imperfect crystals, all bipyramids. The largest crystal from the granular corundum rock was 2 mm. long. The mineral has a specific gravity (by Clerici solution) of 4.00, and a hardness of 8.5.

Nevoria.—The surface specimens obtained a little north of the Never Never G.M. are almost identical with those from Gibraltar except that the margarite is less abundant. Most of it is in coarse scaly bunches, pearly white in colour; there are fewer fine scales scattered through the dense granular grey corundum.

A qualitative analysis of the micaceous mineral proved the presence of SiO_2, Al_2O_3, CaO, MgO, Na_2O and H_2O. It has a specific gravity of 3.03, determined with CH_2I_2 on the fine powder. Scales under the microscope show a low birefringence on the basal plane, with a biaxial figure with rather large 2E. These results are typical of margarite.

The granular massive corundum varies from pale to dark grey in colour. One of the cleanest fragments has a specific gravity of 3.8, a low result for corundum due to microscopic pores and inclusions. Under the microscope it is transparent and mostly colourless, but occasional fragments or portions of fragments are sapphire blue in colour. No crystals were observed in the 0.25 mm. powder, but occasional prism and pyramid faces a few mm. long are to be seen on some of the hand specimens. The hardness is typical.

(6) REINITE AND SCHEELITE, JIMPERDING, S.W.

$FeWO_4$ occurs almost exclusively in nature in forms belonging to the monoclinic system, and known as ferberite. In 1878, however, some tetragonal crystals of this compound were found at Mt. Kimbo in Japan and described as a new species under the name of Reinite. Doubt has since arisen as to whether the tetragonal form is natural to $FeWO_4$ or only arises by replacement of crystals of scheelite ($CaWO_4$) by the corresponding iron compound. In this case reinite would not be an independent species.

In a quartz reef which was opened up in 1930 in search of gold in the Jimperding Valley, several tetragonal crystals of reinite were found which are undoubtedly merely pseudomorphs after scheelite, since in several of them part of the original yellow scheelite is plainly visible. The crystals range from 5 to 20 mm. in length and are simple unit bipyramids in form. Angles calculated and measured on the largest crystal are—

	p^1p^2	p^1p_1
Calculated	79°55′	49°27′
Measured	80°	50°

This crystal weighed 6 grms. and had a specific gravity of 6.73 as compared with 6.10 for scheelite and 7.40 for ferberite.

Cross fractures show in most of the crystals a number of small remnants of yellow scheelite embedded in the brownish black reinite. The surface portions have been almost completely altered, scheelite only rarely showing in quite small areas.

Reinite does not appear to have been previously observed anywhere in the Commonwealth.

(7) VARISCITE (REDONDITE) AND LEUCOPHOSPHITE (Sp. nov.), NINGHANBOUN HILLS, S.W.

At the extreme eastern end of the Ninghanboun Hills, on the shore of Lake Weelhamby (a large salina), is a knoll of sepentine reaching to about 100 ft. above the lake level. The rock in this hill is extraordinarily dismembered by three sets of cracks approximately at right angles to one another,

and following the east and west cracks are two vertical veins about 2 ft. wide, passing over the summit of the hill about 30 ft. apart, and filled with a multicoloured mass of phosphates. The filling is not wholly confined to the two main seams, but extends from them for a greater or less distance into the other series of cracks, a considerable mass showing in a horizonal seam on the east side of the hill.

The veins are vughy or cavernous, some spaces being large enough to admit a man or a wallaby, a few of which obviously frequent them. On a smaller scale the filling is found to be porous, varying in texture from that of a hard or soft chalk to pumiceous, or crustiform with longitudinal crevices. The colour covers a wide range from almost pure white, through greyish-white and greenish-white to French green (R 35″ i), Montpellier green (37″ i) and nickel-green (37″ m) in one direction, and through various tints of pinkish buff and lighter brown to hair-brown (R 17⁴ i) in another. Green is the more common colour.

Despite the apparent wide range of material contained in the veins, actual analysis shows the filling to be almost wholly redondite, a ferriferous variety of variscite, intimately mixed with granular chalcedony and opal. The varying colour appears to be due to uneven distribution of staining agents, chromium phosphate being responsible for the various shades of green, and iron and possibly manganese compounds for the buff and brown. The purest variscite, as well as that which contains appreciable quantities of isomorphous ferric phosphate, is apparently white.

A close examination of the structure of the filling reveals several stages in the deposition of the phosphates associated with corresponding colour variations. It is quite plain that much of the present filling is a replacement in situ of angular blocks of the serpentine, ranging in size from a few millimetres to many centimetres in diameter. In an excavation on the northern vein are exposed one or two large blocks of the dark green rock which were fresh in the centre but have been altered into a grey mixture of variscite and chalcedony to a depth of about a centimetre all round. Such a crust was found to contain 3.69 per cent. of P_2O_5 and 64.32 per cent. of silica. Other large boulders have been completely phosphatised, but show remnants of their original structure, particularly of a subfibrous actinolite. A typical specimen of this nature is mottled white, pale green and pale brown in colour, carrying in bulk 6.86 per cent. of P_2O_5 and 62 per cent. of silica and insoluble silicates. It is traversed by veinlets of dull green opal.

The brightest green material in the deposits is almost wholly in angular fragments, both small and large, and more rarely in lamellar, crustiform, masses. The angular masses, which are obviously replacements, are embedded in a porous mass of white or tinted material, which will be referred to as the matrix.

A third structural feature is the presence of a fair number of sharply defined veinlets in the matrix, from a millimetre or two, to one or two centimetres in width. The narrowest of these are often filled with opal, the wider ones with buff or brownish redondite, a typical veinlet carrying 27.55 per cent. of acid soluble P_2O_5 combined with alumina and iron, and contaminated with 23 per cent. of silica, no lime being present.

Dealing with the chemical composition of the vein filling it is to be remembered that variscite, $AlPO_4.2H_2O$ and strengite, $FePO_4.2H_2O$ are completely isomorphous, and a complete series of intermediate cocrystallisations are known. Of these the ferriferous varieties of variscite have been called redondite, and the aluminous varieties of strengite, barrandite. $CrPO_4.2H_2O$ in small quantities is present in many occurrences.

One very white, chalk-like mass from the matrix, proved on analysis to be a mixture of granular chalcedony and a hydrous phosphate of potassium, iron and aluminium, the iron predominating over the aluminium. Its analysis is given in column 3 of the table. Such a mineral has not previously been recorded, though a related mineral is known, viz. minervite, a hydrous phosphate of potassium and aluminium with traces of iron replacing part of the aluminium. The formula of minervite is not definitely known, but may be approximately $H_2KAl_2(PO_4)_3.7H_2O$.

A typical specimen of the new Ninghanboun phosphate taken for analysis was found to contain insoluble matter amounting to 55·33 per cent. made up as follows:—

	per cent.
Chalcedony, quartz and traces of combined SiO_2 ...	52·75
Chromite	1·07
Rutile	·48
Carbon, etc.	1·03

The remaining figures yield the formula:—

$$K_2(Fe,Al)_7(OH)_{11}(PO_4)_4\cdot 6H_2O.$$

This compound is insoluble in water, but wholly soluble in hot strong HCl. In view of the large deductions and single analysis the formula is tentative. Neither can its physical properties be closely defined owing to its porosity and intimate contamination, but by heavy solutions its specific gravity has been shown to be between 2.30 and 2.65. In mass the mineral is white in colour and chalky in texture. Under the microscope it is minutely granular and birefringent and practically inseparable by eye or by heavy solutions from the accompanying granular chalcedony. As indicated above its minor contaminations are chromite, rutile, opal, carbonaceous matter, and possibly talc or serpentine. The type specimen is being divided between the British Museum, the Western Australian Museum and the writer's collections.

A second specimen of similar texture, by its mottled pale green tint merging into white, was plainly contaminated with chromiferous redondite, as well as with 46.9 per cent. of silica. It was found to contain, after rejecting the silica, P_2O_5, 36.63 per cent.; K_2O, 4.65 per cent.; $(NH_4)_2O$, 0.04 per cent. This indicates a mixture of about 55 per cent. of the new mineral with 45 per cent. of redondite.

The presence of distinct traces of ammonia in the mineral is noteworthy. A second series of chips from the first analysed specimen gave 0.05 per cent. $(NH_4)_2O$ with only 38 per cent. of insoluble silica.

No previously described mineral approaches this in composition except minervite, a potassium aluminium phosphate, from which it differs in possessing a much greater basicity, a lower ratio of K to (Al + Fe), and finally a molecular preponderance of iron over aluminium. It appears therefore to be a new species for which the name Leucophosphite is suggested (Gr. *leukos,* white; *phosphoros,* the root of phosphate).

PHOSPHATIC MINERALS, NINGHANBOUN.

No. ...	(1)		(2)		(3)	
Mineral ...	Redondite.		Redondite.		Leucophosphite.	
Colour ...	Brown.		Green.		White.	
	%	mols.	%	mols.	%	mols.
Al_2O_3	17·81	175	20·45	201	12·73	125
Fe_2O_3	17·66	110	12·66	79	32·82	206
Cr_2O_3	tr.	—	·73	5	nil	—
FeO	·03	4	·20	3	nil	—
MnO	·27		nil	—	·22	3
MgO	·27	7	nil	—	·73	18
CaO	nil	—	nil	—	tr.	—
$(NH_4)_2O$ ...	tr.	—	tr.	—	·09	2
Na_2O	·19	3	tr.	—	·13	2
K_2O	·29	3	·96	10	7·88	84
H_2O + ...	19·82	1100	20·98	1164	12·28	681
P_2O_5	40·23	283	42·19	297	26·69	188
NiO	—	—	nil	—	tr.	—
CO_2	—	—	nil	—	·17	—
Carbon ...	nil	—	nil	—	tr.	—
SiO_2	1·92	—	nil	—	nil	—
TiO_2	·45	6	·21	—	nil	—
H_2O — ...	1·14	63	1·97	109	6·59	366
	100·08		100·35		100·33	
G	2·60	...	2·44	...	2·45 ±	...

Analyst—D. G. Murray.

(1) After deducting 24·44% quartz and chalcedony, 0·45 % rutile, 0·59% chromite.
(2) After deducting 0·76% quartz and chalcedony, 0·20% rutile, 0·26% chromite.
(3) After deducting 52·75% quartz and chalcedony, 0·48% rutile, 1·07% chromite, and 1·03% carbon, etc.

Apart from the two masses just described, all the other specimens collected from these veins proved on analysis to consist essentially of ferriferous variscite (redondite) contaminated with finely granular chalcedony and opal. Complete analyses were made of two very different looking specimens of the mineral. One was a large bright green (about 37″a) angular fragment picked out of a buff coloured matrix in the northern vein. The analysis is given in Col. 2 of the Table. The green colour is obviously due to the presence of $CrPO_4.2H_2O$. Other green specimens were partly analysed to confirm this impression, the figures obtained being:—

REDONDITE, NINGHANBOUN.

Colour :	Bright green.	Brown spotted with white and green.	Green and brown mottled.	Green, brown and white banded.
P_2O_5	37·93	12·72	39·07	36·50
F_2O_3	12·64	7·94	17·58	19·07
Cr_2O_3 sol. in HCl	·71	·20	·53	·42
Cr_2O_3 insol. in HCl	·31	·06	·37	·28
Insol. SiO_2, etc. ...	4·32	60·49	2·61	5·56

In each instance the insoluble Cr_2O_3 was shown to be present as granular chromite, a mineral found throughout the serpentine mass.

The other specimen analysed (Col. 1) was portion of a hair-brown, hard, slightly scoriaceous mass forming a lens in the southern vein. This also proved to be redondite, but differed from the green mineral in containing more iron as well as a little manganese and magnesia. No acid soluble chromium was present, but fine granules of chromite were distributed through the mass as in all the other specimens analysed. A section made of this material discloses a greenish brown base of minutely granular birefringent redondite in which are set rounded grains of phosphatised rock with angular and rounded quartz grains and black chromite, as well as an occasional cavity filling of chalcedony.

The small amount of acid soluble potash in both (1) and (2) suggests the presence of a small proportion of the new mineral leucophosphite in intimate association with the variscite.

The problem of the origin of the veins presents many points of interest. The nature of the enclosing rock, the many evidences of replacement of it by the vein filling, and the absence of lime, rule out sedimentary beds of organically derived apatite, or crystalline veins or pockets of apatite of the Canadian or Norwegian type. An origin to be considered is a vein or veins of pegmatite carrying such phosphatic minerals as amblygonite, childrenite, triphylite or zwieselite. Such minerals are, however, invariably associated with considerable quantities of coarsely crystallised quartz, felspar, mica, etc., no remnants of which, or of possible pseudomorphs after them, could be seen at Ninghanboun.

The Author's explanation is as follows:—

In recent geological times Weelhamby Lake was a lake in fact as well as in name, and carried abundant living organisms, fish, crustacea, etc., attractive to such birds as cormorants. The serpentine hillock, right on the water's edge, having a wide outlook, and being almost barren of soil and vegetation, formed a convenient roosting ground for large flocks of such birds. Their guano collected on the surface of it and in solution and suspension was carried into the numerous cracks in the rock, particularly into two which were rather larger than the others and reached to the very summit of the hillock. The chemically active ammonium phosphate of the guano attacked the susceptible serpentine, chlorite and other silicates of the rock, producing as the end product of a series of reactions, the highly stable aluminium-iron phosphate redondite in the form of replacement veins and fissure fillings.

The arguments in favour of this theory, apart from its inherent possibility, and the previously stated arguments against a derivation from the normal apatite bed or vein, or a phosphatic pegmatite, are the following:— The abundant evidence of the replacement of the serpentine rock owing to attack by a soluble phosphate. This evidence is both structural and constitutional, especially the presence of pseudomorphs after amphibole and visible partial and complete replacements of masses of the serpentine rock. Again there is the regular distribution of granules of chromite through all the specimens examined. Another point of evidence is the presence, in all specimens, of angular and rounded granules of quartz and rarely microcline, both foreign to the matrix but such as might be carried to their roost by the

birds on their feet. Furthermore, distinct traces of ammonia were detected in such specimens as were examined for it. Finally, certain obscure structures in the veins appear to be chalcedony or opal pseudomorphs after fragments of mollusc shells. It is to be noted that the redondite of Martinique and Redonda Is. is considered to have been produced by the action of guano on andesite; that of Clipperton Is. by similar action on trachyte; the variscite of Connetable Is. from the same action on amphibolite; and the minervite of Reunion Is. from the same action on basalt.

SUMMARY.

A description is given of the occurrence and physical and chemical properties of (1) Chrysoberyl and associated minerals (Cummingtonite, etc.) at Dowerin, this being the first record of Chrysoberyl in the State; (2) Columbite and Tapiolite at Jimperding; (3) Corundum in the Lower Chittering Valley; (4) Diopside at Nevoria; (5) Margarite and Corundum at Gibraltar and Nevoria, the first record of Margarite in the State; (6) Reinite and Scheelite, Jimperding, the first record of Reinite in the State; (7) Variscite and Leucophosphite (a new hydrous phosphate of potash and iron) at Ninghanboun, the first record of both in the State.

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7.—THE OCCURRENCE OF ANDALUSITE, KYANITE, SILLIMANITE AND STAUROLITE IN THE CHITTERING VALLEY.

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The Chittering valley runs almost due south, with some minor bends, along the 116th meridian for 35 miles from a little south of Wannamal to its junction with the Swan valley east of Bullsbrook. The stream has been guided in its flow by a series of Precambrian schists and granitic gneisses which strike approximately north, and are apparently vertically bedded. Both classes of rock are intersected by greenstone dykes, which are mostly either massive epidiorites or hornblende schists.

The sedimentary schists are characterised throughout by an abundance of quartz and biotite, associated with variable amounts of muscovite and chlorite. The relative proportions of biotite and quartz vary from point to point, and bed to bed, the rocks ranging from micaceous sandstones to biotite schists. Small quartz veins and lenses are common in them, and still smaller veins and ill-defined masses of pegmatite are present, but are rather rare. Owing to deep seated alteration, kyanite, sillimanite and staurolite have been generated in a number of places, and andalusite and corundum in at least one. The original rocks have apparently been sandstones and shales, both probably glauconitic or tuffaceous, which would account for the unusual conjunction of quartz and biotite, and for part, at least, of the high content of the rocks in potash and iron.

Sillimanite seems to be confined to the more siliceous rocks. Kyanite and staurolite occur in all types, but the largest and most abundant staurolite is in the most highly biotitic rocks. Both minerals are often more plentiful in the immediate walls of quartz veins, and several occurrences are known of kyanite embedded in vein quartz. Staurolite is not found actually in vein quartz, and only one occurrence is known of its matrix being a pegmatite.

The areas in which the minerals have been studied are, in order from south to north.

Lower Chittering—Bullsbrook Road, Marbling Brook, Goyamin Pool.

Middle Chittering—Toodyay Road, Chittering Lake, South Bindoon.

Upper Chittering—Wattle Flat.

Further north, on the same strike, specimens of kyanite have been sent to the writer from Wannamal, and he has examined in person an extensive development of staurolite schist at Gillingarra. These places are respectively seven and 21 miles north of Wattle Flat, beyond the head of the Chittering Valley, but on what is undoubtedly an extension of the Chittering rocks.

Bullsbrook Road (Lower Chittering). This includes the country within a three-mile radius of C.G.* 200, where the road running east from Bullsbrook impinges on the Chittering Brook, four miles N. of its confluence with the Swan.

In the valley running east through C.G. 1260, J. E. Wells first found the only evidence of *andalusite* in the Chittering Valley in the form of large and small subangular pseudomorphs of muscovite after andalusite, plentifully embedded in a series of beds of mica schist interstratified with bands of granite, striking about 350 deg. The two rocks are in bands 10 to 50 yards (10 to 45 metres) wide, traversed at intervals by small epidiorite dykes. At first sight the "eyes" or "knots" in the schist resemble some of those of fresh andalusite in the Jimperding Valley 14 miles to the north-east, but their softness indicates their alteration, and this is confirmed by microscopic examination. A section of a typical pseudomorph shows it to be almost wholly composed of minutely scaly muscovite, slightly iron-stained, and enclosing a few brown granular masses of altered chlorite, and occasional large scales of muscovite. These pseudomorphs range from one to 10 cm. in length and reach 200 grams in weight. One band of schist in this series carries corundum, the individual crystals of which are also either wholly or partly altered to sericite.†

Near the east boundary of C.G. 826, and on the south side of Plunkett's Mill road, there is a siliceous mica schist, much contorted and weathered in which both sillimanite and kyanite occur in conjunction. *Sillimanite* is by far the more plentiful and forms a considerable proportion of the whole rock, mostly in dense fibrous bundles of milk white colour and satiny sheen, reaching a centimetre in diameter, and six centimetres in length. In addition, it is seen in thin lenses and fan-like groups of fibres. In some specimens sillimanite constitutes 30 to 40 per cent. of the whole rock. Some of the mineral from a large bundle was found to have a specific gravity between 3.15 and 3.25, and to show straight extinction, with elongation optically positive. The associated *kyanite* is in single isolated colourless crystals 2 to 3 mm. long and about 0.5 mm. in diameter. They are fairly common in the more micaceous layers and possess the characteristic angular forms with oblique extinction. A few yards east of the sillimanite rock is a band of quartz-mica schist thickly studded with small white or yellowish kyanite crystals.

From the summit of the range about a mile east of C.G. 818 come the most beautiful specimens of *kyanite* obtainable in the Chittering Valley. This occurrence has already been referred to by the writer in a previous contribution.‡ Here large transparent and translucent crystals occur in vein quartz, the colours ranging from "orient blue," through "Alice blue" to "sky grey" (R 45″ to 45″ f), rarely "sky blue" (47′ d) or "Yale blue" (47′ b). At the extreme northern end of the vein some of the kyanite is quite colourless and associated with other crystals just faintly tinged with blue. The vein has been traced for about 50 yards (45 metres) on a bearing 340 deg. following the contact of a greenstone dyke with a mica schist. At the south end it passes under primary laterite; at the north end it is cut off by a cross dyke of greenstone.

* C.G. = Crown Grant. † See this volume, p. 66. ‡ J.R.S.W.A. 12, pp. 62, 63.

Marbling Brook. The hill on C.G. 570 immediately to the north of the junction of Marbling Brook and Chittering Brook is composed of beds of gneiss, mica schist, staurolite-mica schist and garnetiferous schist. The *staurolite* occurs in two beds separated by a narrow band of gneiss. The rocks containing it consist largely of quartz and biotite, and are thinly foliated. For the most part the staurolite is in small brown grains and imperfect crystals up to 2 or 3 mm. long, fairly evenly distributed through the rock. Less commonly it has collected into much larger crystals, up to 10 mm., scattered sparsely through the rock.

So far no andalusite, sillimanite or kyanite has been found at this point, which is the furthest south of the staurolite localities.

Goyamin Pool. This is about 4½ miles N.N.E. of the blue kyanite locality, already described, and 3 miles E.N.E. of Marbling Brook. Just to the north-east of the pool is a ridge running east and west which is about 150ft. high. Through it runs a series of schists with a strike about 360 deg. From west to east the succession is: West—(1) large epidiorite dyke; (2) wide stretch of sillimanite schist; (3) narrow band of staurolite schist; (4) kyanite schist; (5) sillimanite schist; (6) kyanite schist; (7) sillimanite schist; (8) dyke and gneiss.

With the exception of portion of the staurolite schist which is highly biotitic, the other rocks are all highly siliceous, carrying 70 to 80 per cent. of fine to coarse quartz grains, the balance being mainly biotite and the characteristic secondary mineral.

The schists which carry the *sillimanite* have the appearance, where weathered, of grey, brown or purplish sandstones of fine to quite coarse texture. They are distinguished, however, by thin lenses of pure white sillimanite following the bedding. These are usually from 0.5 to 2.0 mm. thick and 0.5 to 3.0 cm. long on the cross fracture, and equally wide on the bedding planes. Some material scraped from the lenses was minutely fibrous, colourless and perfectly transparent, with straight extinction and positive elongation. A cross section of the rock shows abundant quartz grains with interleaved biotite, both minerals frequently penetrated by numerous spicules of sillimanite. The visible lenses of the latter appear under the microscope as bundles of almost parallel fibres, sometimes spreading slightly fanwise. Many fibres are bent, others interrupted by gaps in their length. They are from 0.01 to 0.08 mm. in diameter.

One small specimen picked up on this ridge shows satiny and curved masses of white sillimanite with a felt of minute scales of muscovite forming a thin layer on the surface of a quartz vein.

About a quarter of a mile eastwards is a second narrower band of similar sillimanite sandstone or schist, whilst half a mile south-east of Goyamin Pool J. E. Wells has picked up boulders of what is probably the southward extension of the main bed.

A few hundred yards north of the ridge large tough boulders, up to 3 kgm. in weight, of almost pure sillimanite have been picked up on the surface. Their original source is unknown. The only contaminating mineral is quartz which forms about 10 per cent. of the whole mass. The fibrous structure is not everywhere appreciable on the corroded surface, but on a fresh fracture the sillimanite is seen to form a very coarse felt of dense fibrous masses, white, cream-coloured, or pale grey, with a little interstitial

quartz, which itself is penetrated by numerous sillimanite fibres, as shown by the microscope. The specific gravity of the mineral lies between 3.15 and 3.25 and it possesses a straight extinction with positive elongation.

A single somewhat similar specimen picked up a few hundred yards to the north-east consists of practically pure fibrous sillimanite with parallel fibres throughout, reaching a length of 7 cm. It is greyish to yellowish-white in colour, has a specific gravity of 3.26, with Ng slightly over and Np slightly under 1.660. The extinction is straight and elongation positive. Another loose boulder resembles a compressed mass of chips of light brown wood.

There are two beds of *kyanite* schist here, neither of them over two chains (40 metres) wide. Originally the rocks have ranged from a fine sandstone to a coarse grit in texture, and now show in many hand specimens abundant colourless kyanite prisms from almost microscopic size to a maximum of about 3 x 1.5 mm. The relative abundance of visible kyanite varies greatly in different parts of the outcrops. At the surface the rocks are all weathered and ironstained. A section shows about 80 per cent. of quartz grains with strings of heavily ironstained chlorite, probably pseudomorphous after biotite. Many typical kyanite grains are present, usually embedded in the chlorite, whilst small grains of staurolite are not rare, and usually closely associated with the kyanite. Other hand specimens show a fair proportion of a white mica.

In addition to the microscopic *staurolite* above described, a narrow band of schist with visible staurolite occupies a saddle in the ridge, where it lies between kyanite schist and sillimanite schist. Several types of the rock have been recognised. One is highly siliceous and coarsely granular, with staurolite in rather small but abundant grains, and imperfect crystals reaching at most 3 mm. in length. A second is highly biotitic, and in this the secondary mineral is larger, reaching 1 cm. in length, but is very rarely sharply defined by crystal faces. Another of limited extent has a large proportion of creamy white sericite, in which are embedded odd grains and crystals of staurolite up to 5 mm. in length.

To the north, across a small amphitheatre, the staurolite schists outcrop in their least weathered form. The rock is very dark in colour owing to the preponderant biotite and is studded with more or less well formed staurolite crystals up to a centimetre in length. Small lenses and knots of felspathic pegmatite appear in the rock. A section shows the principal constituents of the rock to be biotite, quartz, staurolite and felspar (both microcline and plagioclase). The rock has been analysed by Mr. C. J. LeMesurier with the following results:—

STAUROLITE SCHIST, GOYAMIN POOL.

SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O
53·01	20·38	3·39	7·44	·09	4·53	2·70	2·07	3·43

H_2O +	H_2O —	TiO_2	CO_2	P_2O_5	FeS_2	Total.	G
1·30	·07	1·18	·45	·11	·08	100·23	2·84

An associated pegmatite "knot" is composed of quartz, microcline, and plagioclase. The largest pegmatite mass in this rock outcrop is about one metre wide and is composed mainly of finely granular albite with subordinate quartz, muscovite and microcline. It is remarkable in containing many crystals of staurolite from a few millimetres up to 2 centimetres in length,

These show the combination *b c m r*, a few being twinned. This is the only case in the writer's knowledge of staurolite being found in a pegmatite, except for one in Canada recorded by W. H. Collins in 1925.

Toodyay Road. Near the N.W. corner of C.G. 145, three-quarters of a mile north of the branch road to Toodyay, sillimanite, kyanite and staurolite have been found in close association.

So far the only specimens of *sillimanite* collected have been three loose boulders, one being practically pure sillimanite, the other two a mixture of this mineral with quartz and a little kyanite.*

The first specimen looks extremely like a number of large chips of silky grained and slightly knotted wood which have been compressed into a solid block. It is unevenly ironstained and is composed of a number of large flat bundles of fine fibres reaching two or three inches (5 to 8 cm.) in length. Some of the cleanest mineral, floated and purified from the attached iron stain, had the following composition:—

SILLIMANITE, MIDDLE CHITTERING VALLEY.

	SiO_2	Al_2O_3	Fe_2O_3	Mn_2O_3	CaO	MgO	H_2O+	H_2O-	Total.	G
Per cent.	41·34	57·22	·90	·15	*nil*	*nil*	·73	·05	100·39	3·15
Mols. ...	688	561	6	1	—	—	45	—		

Analyst: D. G. Murray.

This points to a mixture of about 92.5 per cent. of sillimanite with 7.5 per cent. of quartz (and opal?). With the unaided eye, or mounted in the ordinary way under the microscope, the free silica could not be detected, though apparently it had not all been removed by the preliminary flotation of the mineral with various strengths of CH_2I_2. During the determination of the refractive indices by immersion, the free silica was, however, plainly detectable by its lower refractive index, when immersed in a liquid with the mean index of sillimanite, 1.655. It was found to form thin films on and interstitial fillings between, the individual fibres of the sillimanite bundles, and more rarely to be present as granules traversed in all directions by sillimanite fibres.

The calculated mixture should have a specific gravity of 3.19, if sillimanite be taken at 3.25, and quartz at 2.65. The lower value observed, 3.15, is explained by the hydration of one or both minerals.

The separated sillimanite fibres are colourless and transparent under the microscope, with straight extinction and positive elongation. The refractive indices were determined to be 1.674, 1.656, 1.6545.

The other two specimens consist of vein quartz with some woody-looking masses of sillimanite on one face of each. On the same faces are a few yellowish crystals of kyanite, a millimetre or less in diameter.

This is the furthest north at which sillimanite has been observed.

Kyanite, in addition to the above, is abundant over the slopes of the hill on the southwest side of the road in loose boulders and in a quartz outcrop. It is found in two matrices, viz., in a quartz biotite schist, and in vein quartz. The schist is a reddish rock, banded, but not strongly foliated. The surface is often fairly thickly studded with kyanite prisms up to 8 x 2 mm. These are more abundant in certain thin bands than in the main mass of the

* Since this was written J. E. Wells has discovered sillimanite in several forms to be abundant half a mile due east of this point.

rock. A section of the latter shows rather coarsely granular quartz with biotite and muscovite, approximately in the relative proportions of 80, 12, 8 respectively. A few imperfect crystals of kyanite are noticeable and films of limonite resulting from the partial weathering of the biotite. The kyanite is either colourless, greyish-white, or yellowish-white to the unaided eye.

A large quartz outcrop carries abundant kyanite, particularly in irregular films of mica (biotite and muscovite) which traverse it. In these the prisms reach 2 cm. in length and 4 mm. in width. They are not confined to the micaceous layers, but are much more abundant in them than in the solid quartz. In colour they are either pale yellow, colourless, or white, and in the mica are not infrequently curved, sometimes quite sharply. A concentrate under the microscope showed typical optical properties and revealed an occasional small terminated crystal resembling Danas Fig. 1 on p. 500 of the 7th Edition of his System of Mineralogy.

Very little *staurolite* was observed at this point. Some small crystals and grains were, however, seen in a weathered biotite-quartz schist, and in a boulder of coarsely granular quartz with a little mica. The exact nature of the latter rock is uncertain. A section of the former reveals its constituents (in order of abundance) as: quartz, biotite (partly chloritised), muscovite, staurolite (in ragged grains) and limonite. There are minute inclusions of zircon, etc., in the quartz.

Chittering Lake. The high ridge on the east side of the south end of Chittering Lake has a hard band of granite gneiss on its western end, immediately east of which is a wide series of highly biotitic schists, striking north, and intruded by occasional dykes of epidiorite and hornblende schist.

No sillimanite has been observed at this point.

On the crest of the ridge, about half a mile east of the lake, one band of biotite schist carries *kyanite*, and in places is thickly studded with crystals. These range in size from 5 x 1 mm. to 5 x 1 cm. They are all appreciably blue in colour, the most pronounced being "tyrian blue" (R 47″ i). They are not very transparent, though in some crystals light can be seen through a thickness of 2 mm. One very pale blue crystal 3 mm. thick in two directions is completely transparent. The form in every case is the usual almost rectangular prism with ragged ends. Loose crystals can be found in the soil.

In this place *staurolite* is particularly abundant and better crystallised than anywhere else in the Chittering Valley. In greater or less quantity it is found all across the strike of the schists for about half a mile, some bands being thickly studded with crystals. The matrix is invariably a biotite quartz schist, thinly foliated, and usually containing a high proportion of black biotite. Where the rock is darkest the included staurolite is nearly black in colour; where the rock is paler, the staurolite too is much lighter in colour, about kaiser brown (R. 9′ k). The lighter crystals are usually smaller (3 x 1 or 4 x 2 mm.) and less perfectly developed. In the darker rocks crystals 4 x 2 to 6 x 4 mm. are common. The forms usually developed are *b* (010), *c* (001), *m* (110) and often *r* (101). The basal plane is usually very dull even when the other faces, especially (010) have a brilliant lustre.

In the sides and on the dump of a shallow well, close to the kyanite band on the crest of the ridge, the largest and best developed crystals of staurolite were found. They vary from 5 x 3 up to 20 x 15 mm. in size and

are quite frequently twinned. These twins form oblique or rectangular crosses, the former, which are the more common, being twins on z (232), the latter on r (032).

A series of measurements of some of the best crystals from this place were made with a Goldschmidt's goniometer by Miss E. A. Bowley, Mr. H. Bowley, and the writer. The significant results, as compared with previous data, are—

	Goldschmidt.	Dana.	Hintze.	E.S.S.	E.A.B. & H.B.
m^1m^4 ...	50°36′	50°40′	50°34′	50°41′	50°37′
				50°41′	50°38′
					50°41′
cr ...	55°14′	55°16′	55°14′	55°17′	55°18′
					55°18′

The mean readings for Chittering Lake staurolite are mm 50° 39½′, cr 55° 17½′ from which the calculated axial ratios are 0.4732; 1 : 0.6832.

In comparing these figures with those of Dana and Goldschmidt one must remember that the orientation differs with the two authors, Dana's b axis being Goldschmidt's c axis.

An analysis was made of several of the freshest and cleanest looking crystals having a specific gravity ranging from 3.68 to 3.73. The results were—

STAUROLITE, CHITTERING LAKE.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O
Per cent. ...	30·08	49·94	1·56	12·98	·42	1·54	·38	·14	·06
Mols. ...	501	490	10	181	6	38	7	3	

	H_2O	TiO_2	Total	G
Per cent.	1·92	·90	99·92	3·705
Mols. ...	107	11		

Analyst: D. G. Murray.

The figures show an appreciable excess (5.5 per cent.) of silica over that required by the accepted formula $HFeAl_5Si_2O_{13}$. There is microscopic evidence that most, if not all, of this excess is present as minute inclusions of quartz. A few small scales of biotite were also embedded in the analysed material.

South Bindoon. Of the four minerals only *kyanite* has been observed here. It occurs four miles north of the previous locality on a northerly spur of Red Hill, near the south-east corner of Loc. 1363. Long narrow, white or grey, crystals are plentiful in thin lenses in a siliceous gneiss, and rarely in vein quartz. Details were given in the *Journal of the Royal Society* in 1926, Vol. XII., pp. 63-64. The gneiss has since been described by R. A. Farquharson* as composed of granular quartz with bands of black and white mica.

Wattle Flat. This is about nine miles N. by W. of South Bindoon. Both *staurolite* and *kyanite* occur near the N.W. corner of Loc. 805 in considerable abundance; descriptions have already been given in the *Journal,* Vol. XII., pp. 64, 65, 66. This is the only place in the Chittering Valley so far known in which garnet is abundant in interbedded gneiss and schist. Further north, however, at Gillingarra, garnet is plentiful in an area characterised by abundant staurolite in mica schist. At Wattle Flat kyanite and staurolite occur

* An. Rept., Geol. Surv. W.A., 1926, p. 24.

in separate bands of a similar rock, viz., a quartz-biotite schist. The kyanite in some bands forms ill defined "eyes" composed of a single kyanite individual enveloping a large percentage of quartz. In others it has well defined prismatic boundaries, crystals ranging from 10 to 60 mm. long. In all cases it is white or pale grey in colour.

The *staurolite* is practically never crystallised here, but occurs as lenticular "eyes" enclosing abundant granules of quartz. The schist as a whole carries 73 per cent. SiO_2 and 13 per cent. Al_2O_3, and is therefore much more quartzose than the Goyamin Pool schist whose analysis is given on p. 78.

SUMMARY.

The strip of country, 35 miles long and four miles wide, which embraces the Chittering Valley, is characterised by highly metamorphosed, probably Precambrian, sediments. These consist mainly of quartz and biotite in varying proportions, with less abundant muscovite and sporadic development of chlorite, kyanite, sillimanite, and staurolite, and more rarely of garnet, andalusite and corundum. Andalusite has been completely micacised, and corundum almost so, in the later stages of alteration, the whole area having been subjected to intense metasomatism in which solutions rich in potash took a prominent part. The type of rock most abundant is a highly biotitic, thinly foliated schist, but there are small local developments of quartzite, biotitic sandstone, and muscovite schist. The sedimentary formation is split up into bands by parallel tongues of granite or granitic gneiss, by which also it is flanked on both sides. The whole complex is traversed by dykes of epidiorite and related greenstones. Small quartz veins are not uncommon, and are intimately associated in several places with the development of kyanite and sillimanite. Small pegmatite veins and "knots" are rare but not unknown in the sediments.

The most important localities for the secondary minerals are—

- Andalusite (mica pseudomorphs)—Bullsbrook Road.
- Kyanite—Bullsbrook Road, Toodyay Road, South Bindoon, Wattle Flat.
- Sillimanite—Goyamin Pool, Toodyay Road.
- Staurolite—Goyamin Pool, Chittering Lake, Wattle Flat.
- Garnet—Wattle Flat.
- Corundum—Bullsbrook Road.

By Authority: FRED. WM. SIMPSON, Government Printer, Perth.

JOURNAL OF THE ROYAL SOCIETY OF WESTERN AUSTRALIA.
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8.—ON HELVITE FROM MT. FRANCISCO, N.W. DIVISION.

By H. BOWLEY, F.A.C.I.

Read 12th April, 1932. Published 24th May, 1932.

Specimens of this rare and peculiar mineral not known to occur anywhere else in Australia were received from the old Congo Lease at Mt. Francisco (Pilbara G.F.) in 1927. It is a sulpho-silicate of beryllium, manganese, iron and zinc. The specimens received were brownish coated angular masses up to 2 inches across. The coating consists of a mixture of limonite and psilomelane derived from the alteration of the mineral: the psilomelane also penetrates into the cleavages. A strong octahedral cleavage was easily recognised on the specimens examined whilst in some cases partly developed octahedrons formed excrescences on the surfaces. Thin splinters are brown in colour, agreeing with Ridgway's 9′ m. "Carob Brown," but the mineral in mass is a mottled brownish black owing to the presence of decomposition products. The mineral is fairly brittle and breaks with an uneven fracture with a resinous lustre. It is isotropic and the refractive index was found to agree with a mixture of arsenic and antimony iodides and piperine in the proportion of 27.5 iodides to 72.5 of piperine, giving a figure for N of 1.765*. The specific gravity was found by immersing the mineral in pure methylene iodide and warming unt'l the test piece was just suspended in the solution, then determining the specific gravity of the liquid at that temperature. This gave a figure of 3.314 for the mineral. The mineral is readily decomposed on warming with 10 E Hydrochloric acid with the evolution of sulphuretted hydrogen and the separation of silica.

The results of an analysis of the Mt. Francisco mineral are given in column A of the table below. The material taken for analysis was carefully selected, the powder being wholly isotropic and showing no signs of alteration products.

In columns B and C are the analytical figures for the type minerals helvite and danalite respectively.

	A. Helvite. Mt. Francisco.		B. Helvite. Schwartzenburg.		C. Danalite. Rockport.	
	%	Mols.	%	Mols.	%	Mols.
SiO_2	31·82	530	33·26	554	31·96	532
BeO	13·90	556	12·03	481	13·86	554
FeO	15·80	220	5·56	77	25·71	358
MnO	28·00	395	41·76	589	6·17	87
ZnO	7·76	95	...	...	19·11	235
S	5·75	179	5·05	157	5·93	185
H_2O	...	...	1·15	64	...	...
	103·03		98·81		102·74	
O = S ...	2·86		2·51		2·96	
	100·17		96·30		99·78	
Fe: Mn: Zn Ratio	1 : 1·8 : 0·4		1 : 7·7 : 0		1 : 0·2 : 0·7	
Be:(Fe, Mn, Zn) Ratio ...	3 : 3·9		3 : 4·2		3 : 3·7	

* This figure was also obtained by the writer for the refractive index of danalite from Rockport in Dr. E. S. Simpson's private collection.

It is to be noted that zinc is not recorded as being present in the helvite from Schwartzenburg. Possibly it was unsuspected and no attempt made to determine its presence or separate it from the manganese.

Helvite and Danalite are two members of an isomorphous group with the general formula $Be_3.R_4.(SiO_4)_3.S$ with R representing Mn, Fe and Zn. The end members of this group are

$Be_3.Mn_4.(SiO_4)_3.S$ Helvite.
$Be_3.Fe_4.(SiO_4)_3.S$ Danalite.
$Be_3.Zn_4.(SiO_4)_3.S$ Unknown.

Numerous complex formula have been put forward for this group but a critical examination of the published analyses suggests that many of them are based on incorrect analytical figures, due, in many cases, to incomplete separation of beryllium from manganese, iron and zinc.

The formula derived from the analysis of the Mt. Francisco mineral is

$BeO_{558}.RO_{710}.SiO_{2\,530}.S_{179}$

This simplified gives

$BeO_{3\cdot 10}.RO_{3\cdot 95}.SiO_{2\,2\cdot 95}.S_{1\cdot 00}$

which may be stated

$Be_{3\cdot 10}.R_{3\cdot 95}.Si_{2.95}.O_{11\cdot 95}.S$

which is very close to the type formula.

The predominating member of the R group in the Western Australian mineral is manganese, the ratio of that constituent to iron and zinc respectively being 1.8 : 1.0 : 0.4, the mineral, therefore, being a ferruginous helvite which has not been previously recorded in this or any other State of the Commonwealth.

By Authority: FRED. WM. SIMPSON, Government Printer, Perth.

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9.—COPPER BUNTICIDES.

By B. L. SOUTHERN, A.A.C.I.

Read 10th May. Published 30th May, 1932.

INTRODUCTION.

In 1925 the Department of Agriculture purchased commercial "copper carbonate" from six different firms in Perth and submitted samples to the Government Chemical Laboratory with a view to determining the best dust based on the suggested standards of Mackie and Briggs. While none of the samples conformed to the standards, the one nearest approaching them gave markedly inferior control of bunt infection in trial plots over several seasons.

The purpose of this investigation has been to determine -

(a) standards for copper dusting powders;

(b) chemical and physical characteristics of the powders;

(c) the action of the powders on bunt spores.

Commercial "copper carbonates" vary in composition and include basic carbonates, basic sulphates, mixtures of these compounds, and oxychlorides. Rarely, if ever, do the prepared compounds approach the constancy of composition of the naturally occurring minerals, their compositions depending entirely on the methods of preparation. Experience in Western Australia suggests that the basic sulphates and mixtures are better controllers of bunt than the basic carbonates, and again, for no apparent reason, some very fine-grained basic sulphates are inferior to coarse-grained ones. Beyond making comparative trials no special work has been done on the oxychlorides.

FIELD TRIALS.

The field trials have been carried out at the Merredin and Chapman experiment farms. Merredin soil may be described as a heavy chocolate loam with a pH value of 7.1. In 1928 experiments were duplicated on another portion of this farm in poor yellow-brown sand containing a small percentage of clay. This soil had a reaction of pH 5.8; it is poor wheat land but grows excellent rye. During the same year small trials were conducted at Applecross, near Perth, in grey sand devoid of clay, reaction pH 6.1 and containing 3 per cent. of organic material. Unfortunately the latter results can only serve as an indication, as a fire destroyed the crop before the harvest was completed.

During the 1925 trials it was shown that the powders almost completely controlled the disease when the rate of infection was one part of bunt spores to 750 parts by weight of wheat and applied at the rate of 2 ozs. per bushel.

In order to show greater differences in effectiveness of the powders the spore dosage was increased to 20 parts, and over later years dropped to 10 parts. A variety of wheat known as *Booran* was first used on account of its low bunt resistance, but was later changed to *Gluyas Early*.

All seeds were infected and treated in the laboratory and placed in test tubes plugged with cotton wool. It was noticed that the basic carbonates had a tendency to lift the spores when shaken in a stoppered bottle with the infected grains. One hundred infected and treated seeds were sown by hand in rows 2¼ links apart, each treatment being repeated five times and planned on the "chess-board" system, with appropriate controls. Details of the cultural methods adopted will be found in the "Journal of Agriculture, W.A." At harvest time the infected and clean plants were counted and the diseased plants expressed as a percentage of the matured ones.

PARTIAL CHEMICAL AND PHYSICAL COMPOSITION OF THE COPPER DUSTS.

Table 1 gives the partial chemical and physical composition of all dusting powders used during the tests:—

TABLE 1.

Sample.	Cu.	CO_2	Acid sol. SO_3	Water sol. SO_3	Combined Cl	Density lbs. per cub. ft.	Retained on 200 mesh sieve
	%	%	%	%	%		%
A 25	46·88	0·88	0·43	3·83	17·09	63·2	43·6
B 25	50·04	17·64	·49	2·54	...	58·5	0·6
C 25	51·08	11·94	6·41	0·98	...	61·0	17·5
D 25	49·88	2·00	17·03	0·72	...	76·9	5·15
E 25	47·76	0·56	19·92	1·61	...	68·1	7·2
F 25	53·48	6·64	12·11	0·82	...	72·2	8·3
A 27	50·4	2·20	...	...	...	89·3	...
B 27	51·44	17·96	...	...	...	53·8	...
A B	52·48	19·32	...	...	...	49·0	3·8
Basic sulphate	52·3	...	16·2	Trace	...	51·0	...
Copper hydroxide ...	63·0	...	...	...	...	...	...
Sm	54·36	...	...	...	15·08	40·2	12·2
Copper acetate	29·96	...	...	...	...	...	...

Uniformity in composition is only shown by the copper content, which averages about 50 per cent. The basic sulphate was prepared by adding recently ignited pure lime to a solution of pure copper sulphate and the calcium sulphate precipitated at the same time washed out with distilled water. Its composition was closely related to $CuSo_4.3Cu(OH)_2$. The copper hydroxide was prepared by adding ammonia to a boiling copper sulphate solution until most of the copper was thrown out as a green precipitate. The precipitate was filtered and washed, treated with strong caustic soda solution for one hour, and again washed by decantation and dried. The copper hydroxide retained its bright colour for several months before finally turning black. The specially prepared samples were ground to pass a 200-mesh sieve. Apparent densities were determined by tamping down on a table an ounce of material in a 50 ml. cylinder until the volume was constant. Density determinations will, however, be discussed later.

At the commencement of this investigation only some of the samples mentioned in Table 1 were used and gave the following results when tested in the field:—

TABLE 2.

—	1925. Spore dosage 1–750; per cent. infected plants.		1926. Spore dosage 20–750; per cent. infected plants.	
	Merredin.	Chapman.	Merredin.	Chapman.
A 25	...	...	34	5
B 25	...	...	44	5
C 25	1	...	48	6
D 25	...	...	24	3
E 25	...	...	49	15
F 25	1	...	31	5
Sm	...	...	40	13
Copper acetate	1	...	42	10
Average controls	22	13	76	83

Attempts which were made to correlate effectiveness of bunt control with the chemical and physical properties of the powders gave abortive results. Sample B25 is the only one approaching the standards recommended by Mackie & Briggs excluding of course A25, Sm and copper acetate, which are special cases. B25 closely resembles a sample of copper carbonate obtained from California and described as a satisfactory powder; unfortunately the latter sample was too small for use in field trials. D25, despite its high density, has proved its efficiency in several types of soils over many years. It is a mixture of basic sulphates and carbonates, while a complete chemical analysis shows its components are not combined in any simple ratio. The local agents for the material have not been able to trace the manufacturers. Apart from confirming these results several lines of attacking the problem presented themselves:—

A. Preparation of other copper dusts of known composition and further trials with additional commercial compounds.

B. Determinations of the amount of powder actually retained on the infected and clean wheat grains.

C. Investigating the relative solubility of the compounds in the soil solution surrounding the germinating wheat grains and spores.

D. Determination of specific chemical and physical characteristics.

PREPARATION OF OTHER COPPER DUSTS OF KNOWN COMPOSITION AND FURTHER TRIALS WITH ADDITIONAL COMMERCIAL COMPOUNDS.

A. For the 1927 trials the coarse oxychloride A25 was ground to pass a 200 mesh sieve to compare it with the original powder. Two new commercial samples were tried, B27 a commercially pure basic carbonate of lower density than B25 and manufactured by the same firm, and another A27 somewhat similar in composition to D25 but of higher density. In addition the basic sulphate previously described (page 86) was tested before washing out the associated gypsum. The results of field trials are given in Table 2.

TABLE 2.

	1927. Spore dosage 20–750; per cent. infected plants.	
	Merredin.	Chapman.
A 25 (ground)	75	7
A 25	77	8
B 25	77	7
C 25	69	6
D 25	63	6
E 25	70	7
F 25	60	7
A 27	61	4
B 27	77	7
Sm	70	5
Basic copper sulphate and gypsum	71	11
Average controls	...	60

Due to secondary causes many of the plants in the control rows failed to reach maturity. The season at Merredin was apparently favourable for the development of bunt as the control by the fungicides was markedly less than in preceding and succeeding years. The differences were small so it is hard to draw definite conclusions. Grinding sample A25 did not improve it. D25 was inferior to F25, and A27 at Merredin was excelled only by A27 at Chapman and equalled by C25. The basic copper sulphate and gypsum mixture was the worst at Chapman and a very poor one at Merredin.

In 1928 the field experiments were modified. It was decided to exclude Chapman farm and duplicate the trials on different soils at Merredin. Samples A25, C25, E25 and F25 were abandoned. Basic copper sulphate washed free of gypsum, a new basic carbonate AB of low density and mixtures of the basic sulphate with AB were included as well as copper hydroxide. The dosage was decreased to 10-750.

TABLE 3.

Spore dosage 10–750 ; per cent. infected plants.

	1928. Merredin Farm.	
	Loam soil.	Sandy soil.
B 25	33	3
D 25	12	*Nil*
A 27	26	3
B 27	51	7
AB	57	12
Basic copper sulphate	21	6
Mixture 1	29	4
,, 2	29	3
,, 3	27	3
,, 4	31	2
,, 5	31	4
Copper hydroxide	31	3
Sm	48	3
Average controls	83	91

The mixtures were prepared by mixing increasing proportions of AB with the basic sulphate in the ratios 1-11, 9, 7, 5 and 4. Mixture 3 had roughly a chemical composition similar to D25.

D25 again showed its ability to control the disease compared with the basic carbonates. All plants, both affected and clean, stooled remarkably well and made excellent growth in the loamy soil while growth generally was stunted and poor in the sand. It is somewhat strange the rate of infection should be much higher in vigorous plants that have a better chance of combating the disease than in the less vigorous ones. The explanation probably lies in the facts that the soil assists the fungicide in its action or the poor plant is an unsuitable host for the fungus.

The addition of basic carbonate to the basic sulphate reduced the fungicidal properties of the basic sulphate in the loam and increased them in the sandy soil. The results so far indicate that those samples which contain a high percentage of basic sulphate are superior to those in which basic carbonate predominates; unfortunately this statement is not absolute as powder E25 used in previous trials provides a notable exception. This powder is almost a pure basic sulphate and though very finely ground it has a high density.

It has been suggested that the copper which is linked to the hydroxyl group in the basic copper salts is the active agent of the fungicide, but the copper hydroxide used in 1928 contained 63 per cent. of copper and only gave average results in the field trials. Calculations have been made of the hydroxide content of many of the dusts used but no relationship exists between the percentage present and the fungicidal properties.

The figures for the Applecross trials are not given; the results indicated, however, that the controls were high while the fungus appeared easy to control. Sodium fluoride was used in one treatment; it did not appear to be effective, and at the same time retarded the germination and development of the plants.

THE AMOUNT OF DUST ACTUALLY RETAINED ON CLEAN AND INFECTED SEED.

Western Australia standard fair average quality wheat was dusted with several of the powders at the rate of 2 ozs. per bushel of wheat. The dusted sample after being thoroughly shaken in a stoppered jar was thrown on to a 30 mesh sieve and gently rolled over the surface to remove the unattached dust. After this it was found that the adhering dust could be removed by adding 2.5 grams of the wheat to 20 mls. of cold .2NHCl allowing the acid to react 4 minutes with constant stirring to dislodge air bubbles clinging to the grain. The mixture was filtered directly into 100 mls. Nessler tubes and washed to 75 mls. with cold distilled water. The copper in the filtrate was then determined by the ferrocyanide method. The acid treated wheat was carefully ashed and no copper was found in the residue.

Another portion of wheat was infected with bunt spores at the rate of 10 parts of spores to 750 parts of wheat by weight. The bunted wheat was then treated with the powders and the adhering dust determined in exactly the same manner as for the clean seed.

Table 4 gives the results of these experiments.

TABLE 4.

Sample.	B25.	D25.	E25.	AB.	Basic sulphate.
Clean Seed— Percentage of added dust adhering	72	60	76	72	76
Bunted Seed— Percentage of added dust adhering	68	88	80	46	84

It was observed that many spores were removed from the grains by AB, and less by B25.

At the heavy spore dosage the spores assist some of the powders to adhere to the grain while other powders remove spores and themselves in the process of treatment. These facts throw doubt on the reliability of field trials, as the actual infected and treated seed sown in the field is sometimes not what it is specified to be. Unless large quantities of material are available it is impossible to determine accurately the amounts of bunt spores dislodged by the powders. Mackie & Briggs have recorded experiments using basic copper carbonate at heavy spore dosages over two seasons. It is presumed the same powder was used. In 1921 and 22 at a spore dosage of 1-30 by weight they obtained the following results by infected heads count:—

	1921.	1922.
	Per cent. bunt.	
Copper carbonate 1 oz. to bushel	30	36.6
„ „ 2 „ „	17.7	46.5
„ „ 4 „ „	3.4	20.0

Their 1921 figures are what one might expect if the powder did not lift the spores. Analogy with sample AB suggests approximately 1 oz. of the carbonate would not dislodge many spores. The 1922 results suggest dislodgment of spores and dust, the dust deficiency being made up at the 4 ozs. rate with, in proportion, fewer spores dislodged compared with dust retained. Admittedly their results are hard to explain unless different powders were used for the different years.

The ratios of powders on bunted seed to powders on clean seed are interesting when compared with the relative efficiency of the powders over a number of years.

TABLE 5.

Sample.			B25.	D25.	E25.	AB.	BS.
Ratio $\left\{\dfrac{\text{powder on bunted seed}}{\text{powder on clean seed}}\right\}$ ...			·94	1·33	1·05	·64	1·11
Dosage—			Percentage Infected Plants.				
20–750	1926	Merredin loam ...	44	24	49	...	...
	„	Chapman	5	3	15	...	...
20–750	1927	Merredin loam ...	77	63	70	...	...
	„	Chapman	7	6	7	...	...
10–750	1928	Merredin loam ...	33	12	...	57	21
	„	Merredin sand ...	3	*Nil*	...	12	6
10–750	1929	Merredin loam ...	12·4	4·4	...	...	2·2
10–750	1931	Merredin loam ...	*Nil*	0·9	...	...	0·7

Generally speaking the samples with the highest ratios are the better bunt controllers, the outstanding exception being E 25. A standard for fineness based on the amount of dust clinging to clean or infected seed does not seem feasible.

All workers on bunt control cannot have failed to notice the great differences in the counts of infected plants in different rows under the same treatment. Similar variations exist in infected and untreated rows, the following figures provide typical examples:—

Variety of Wheat.	Infection 10–750.	Percentage infection per row.					Average.
		Row 1.	Row 2.	Row 3.	Row 4.	Row 5.	
Booran	10–750	74	53	62	80	66	67
Gluyas Early	,,	39·5	40	42	45·25	41·25	41·6
Infected and treated Gluyas Early—							
Copper compound B25	,,	9	6	19	18	10	12·4
Basic sulphate ...	,,	2	1	1	2	5	2·2

Several factors could account for these variations:—

1. Variations in the soil—
   (a) texture,
   (b) moisture content,
   (c) temperature.
2. Distribution of spores over the surface of the grain.
3. Position of the grain in the seed bed.
4. Depth of planting.
5. Method of calculating percentage of infected plants.

1. The average control figures for Merredin loam and sand in 1928 were 83 and 91 per cent. infected plants respectively. The plots on which these experiments were carried out were about half a mile apart and were therefore under similar climatic conditions. Soil temperatures possibly varied. The Chapman soil is somewhat sandier than the Merredin loam, usually the infection is high at Merredin, the year 1926 being a notable exception when the figures were 76 and 83. Twentyman reports variations on different farms in Victoria. While infection varies from year to year in Western Australia the control of the disease by bunticides is easier in lighter soils.

A partially dry seed bed would probably germinate spores but not seed, the spores would develop and then dry off without the germ tubes penetrating the plumule.

The optimum germination temperatures of wheat and bunt differ, the latter being lower. If the wheat plant is germinating slowly due to cold the spore has a better chance of reaching the plumule before its cuticle hardens. A quick growing plant would have a better opportunity to escape infection. On the other hand if it is too cold for wheat germination, the spore will germinate and die before it can penetrate the seedling.

2. On shaking loose spores with wheat in a closed vessel it is noticed that each grain apparently picks up as many spores as its neighbour. The spores cling more readily to some parts of the grain, notably the brush, the remainder spread themselves more or less evenly over the entire surface. It is highly probable that those spores nearest the germ are in a better strategical position to deliver an attack with their germ tubes on the emerging plumule. Particularly would this be the case when conditions were unfavourable for the development of spores. An infected grain planted crease down, *i.e.*, germ up, is less likely to be attacked below the first joint of the young plumule by a germ tube travelling from the brush than from the immediate neighbourhood of the germ. Control experiments in which half the grains were planted crease up and half down were conducted at Applecross in sandy soil; 200 grains in all were sown. No differences were shown in the final count, but it must be admitted the conditions were ideal for spore germination. The counts in each row were equal.

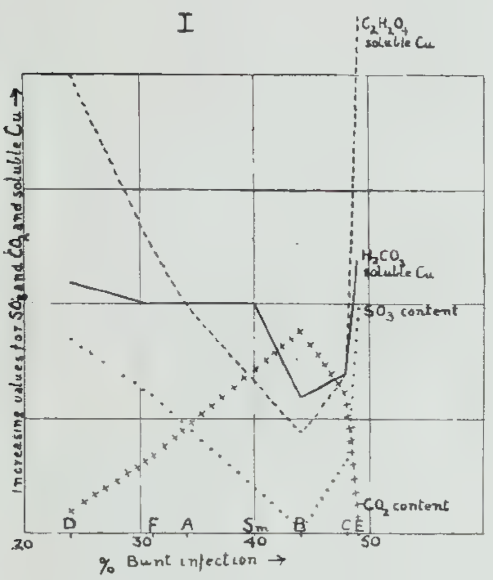
3. By repeating experiments a number of times errors due to an irregular seed bed may be reduced to a minimum when computing a final result. Surface moisture content will vary considerably after rain, particularly on a heavy soil such as Merredin; it might be several days before the moisture content of the mulch is evenly distributed at the depth of planting. The irregular way in which the germinating seed lies combined with variations in the condition of the mulch, is suggested as a reason for fluctuations in the counts of infected plants in different rows. Experience in Western Australia shows infected plants to be grouped together, it being the exception to find an isolated bunted plant between healthy ones. Twentyman in Victoria has made a similar observation.

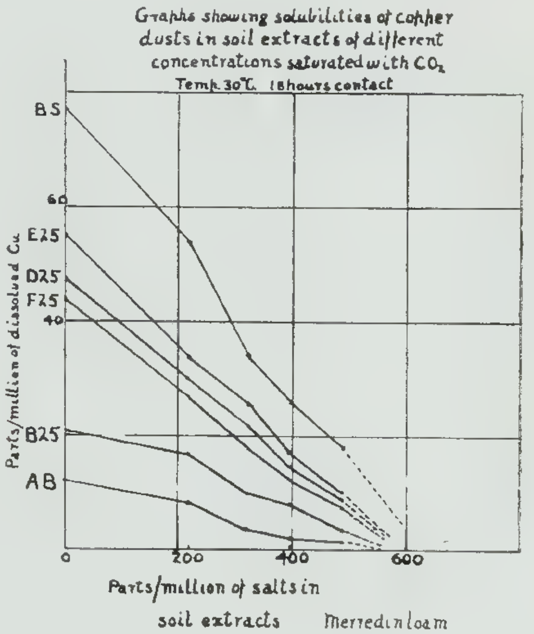
4. Twentyman has carried out experiments planting at different depths but was unable to draw any definite conclusions.

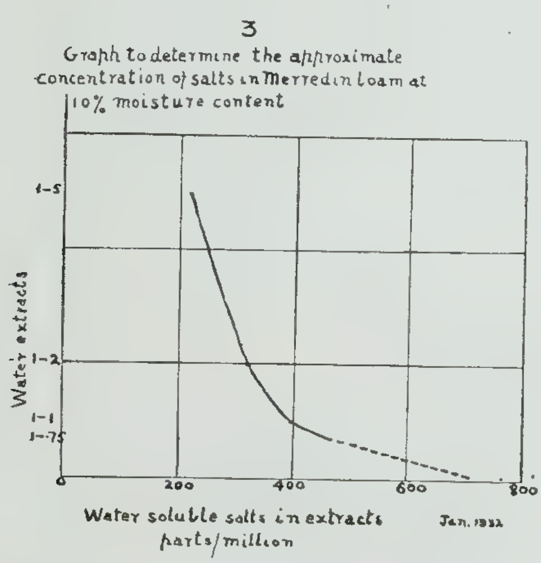
5. Some experimentalists prefer to count bunted heads rather than plants, the reason is difficult to understand. The main function of a bunticide is to prevent disease. There is no evidence that one spore cannot be responsible for infecting every head on a plant, so it seems a plant count gives a better idea of relative efficiency. Percentage infection has been determined by dividing the number of infected plants by the total number matured and multiplying by one hundred. In some cases plants have died after 30 days when final germination counts were taken. It is highly probable most of these were bunted and consequently less able to withstand attacks from other diseases. Were such an assumption correct then the percentages of bunted plants should be higher than reported. More plants die in the infected control rows than the treated ones.

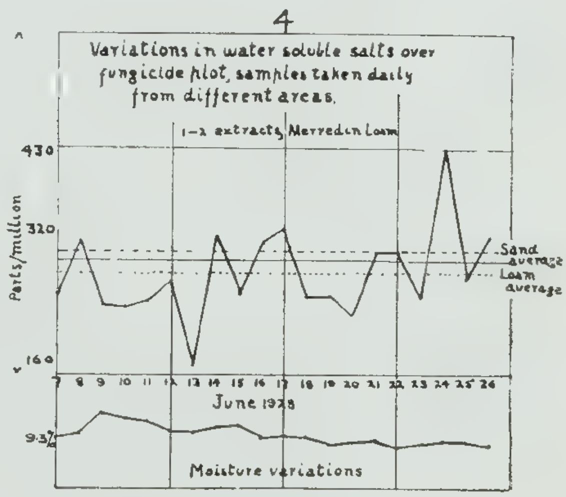
C.—RELATIVE SOLUBILITY OF THE COMPOUNDS IN THE SOIL SOLUTION SURROUNDING THE GERMINATING WHEAT GRAINS AND SPORES.

The marked variations in the counts of the same treatments planted in different rows suggested attacking the problem from a chemical point of view. It was realised that the copper, to be effective, must be dissolved before it can penetrate the spore or its promycelium and germ tubes. The solubilities of the compounds were therefore determined in various solvents. Though insoluble in water the copper dusts were found to dissolve readily in some weak acids and alkalis.









Solubilities in carbonic and oxalic acids increase and decrease depending on the amounts of sulphate and carbonate in the original material. The SO_3 curve in the accompanying graph, No. I., closely follows the H_2CO_3 soluble copper, when allowance is made for the oxychlorides which have been included in the solubility curves as a matter of interest. The graphs are purely relative ones, the determined radicles being plotted against the percentage of infection recorded in 1926 at Merredin. The Chapman figures do not lend themselves to graphing owing to the graphs coinciding in too many places, but the general forms are similar.

The graphs at first sight suggest that a fairly high solubility in H_2CO_3 is necessary for bunt control, but on the other hand too high a solubility is detrimental; this would explain the poor fungicidal properties of E25, but unfortunately a basic sulphate (B.S) was later prepared which had a greater solubility than E25 and was a better bunt controller. It has not yet been shown that during the control of the disease the spore is killed or its germination suppressed by the copper dust, or whether the growth from the spore is poisoned after germination. The solubility suggested that a moderately soluble compound would maintain a lethal dose of copper over a longer period than an insoluble or very soluble one. The soluble copper is precipitated by the soil solution or absorbed by the soil colloids almost as fast as it is dissolved.

To appreciate the H_2CO_3 solubility theory it is necessary to visualize what is taking place in the seed bed. A dry grain covered with an intimate mixture of bunt spores and copper dust lies in a moist bed in fairly close contact with soil particles. Soil moisture passes through the spores and dust into the grain which commences to germinate, giving out CO_2 in the process. After a period of time the soil moisture, *i.e.*, the soil solution immediately in contact with the grain and passing into it, must contain a high percentage of CO_2 derived from the grain and to a lesser extent the soil atmosphere. The possibility of this soil solution saturated with CO_2 dissolving the copper dust has been investigated in detail.

200 grains of *Booran* wheat weighing 9.33 grams were placed on a filter paper in a 200 cc. Erlenmeyer flask containing wet cotton wool and attached to a CO_2 absorption apparatus, using soda lime to absorb the liberated CO_2. The flask was covered with black paper, effectively blocking out the light. At the end of each 24-hours period 2 litres of CO_2 free air were drawn through the apparatus and the absorption tubes weighed. At the end of the experiment water was added to the flask and the contents boiled and 2 litres of air again passed. The following results were obtained:—

Date.	Time.	CO_2 liberated gms.	Temperature.	Remarks.
24–7–28	a.m. 11	...	12 p.m. 65°F	
			2 ,, 67°F	
			5 ,, 67°F	
25–7–28	10	·0154	9 a.m. 58°F	Some embryos showing plumules and radicles, others apparently undeveloped though swollen.
			12 p.m. 63°F	
			2 ,, 65°F	
			3·30 ,, 67°F	
26–7–28	10	·0536	9 a.m. 58°F	Some radicles about $\frac{1}{4}$in. long, plumules short, no sign of chlorophyll, some grains hardly started to germinate.
			10·30 ,, 65°F	
			3 p.m. 70°F	
27–7–28	10	·0918	9·30 a.m. 64°F	Some radicles $\frac{1}{2}$in. long.
28–7–28	10	·0980	9·30 ,, 63°F	Experiment discontinued.
28–7–28	...	·0130	...	After boiling.

Total, CO_2 liberated, ·2718 gram.

One grain of *Booran* wheat therefore liberates 0.001359 gm. of CO_2 when germinated under the above conditions, the percentage CO_2 evolved being 2.913. At a solubility rate of 1,200 parts of CO_2 per million of water, the

CO_2 given off by one grain would be sufficient to saturate 1.1 gms. of soil solution.

The maximum solubility of the copper dusts used was found to be 224 parts per million in CO_2 saturated distilled water at 15°C. Assuming all the CO_2 evolved from 1 grain dissolved in the 1.1 gm. of soil solution, which is very unlikely, the maximum amount of copper dust that could be dissolved would be 0.000246 gm. Dusting at the rate of 2 ozs. per bushel (63 lbs.) the weight of powder retained on 1 grain is 0.0000924 gm., which could be easily dissolved by the CO_2 liberated. A germinating wheat grain will absorb its own weight of moisture up to the first appearance of chlorophyll. This weight represents .047 gm. of water which, when saturated with CO_2, could dissolve 0.0000096 gm. of copper dust. The position is then on excess of CO_2 and an insufficient supply of water for complete solution. If, however, the dissolved dust is absorbed by the spores, grain and soil, then the extra CO_2 will dissolve more dust and so keep up the concentration.

The copper dusts when examined microscopically reveal particles of different sizes. The smaller ones naturally dissolve first. In all solubility determinations excess of dust to solute has been taken, which means that the smaller particles have dissolved leaving the larger ones almost unattacked. Three samples, D25, E25 and B.S., were treated with an excess of H_2CO_3, *i.e.*, an excess above their previously determined solubilities; after 18 hours standing with intermittent shaking each solution contained approximately equal quantities of copper, the coarse particles of each powder remaining undissolved. In D25 some finely divided material remained in suspension, this was basic carbonate contained in the original sample (the basic carbonates are less soluble in H_2CO_3 than the basic sulphates).

Further information, obtained at a later stage in this investigation, definitely shows, however, that the CO_2 theory has little bearing on the method of effecting solution of the copper compounds in the soil solution.

Solubility curves have been plotted showing the dissolved copper in soil extracts of different concentrations and uniform CO_2 content at a temperature of 30°C. The depressing action of the water soluble soil salts in Merredin loam is such that a lethal solution of copper due to CO_2 is never produced.

Soil extracts were prepared by adding air-dried soil to aerated distilled water in the proportions of 5, 2, 1 and .75 parts of water to 1 of soil. After thorough shaking at intervals for half a day the suspensions were allowed to stand overnight and filtered in the morning. Portions of each filtrate were evaporated to dryness and the dissolved salts determined. Over several days each of the filtrates was saturated with CO_2 and 25 ccs. withdrawn and added to .05 gm. of each of the dusts under test contained in a stoppered bottle. The bottles were shaken at intervals for several hours and rested on their sides overnight; the total time of contact was 18 hours and the temperature averaged 30-33°C. The suspensions were filtered in the mornings as rapidly as possible to avoid loss of CO_2, aliquots taken from the filtrates, and the dissolved copper determined by the ferrocyanide method. The curves on the graphs are not perhaps as even as they might be, but with warm weather prevailing the copper was more easily precipitated owing to the rapid loss of CO_2 on exposure of the solution to the atmosphere. Three samples only were filtered at the one time.

Graph No. 2 shows the rapid falling off in the solubility of the dusts with the increase in the concentration of the salts. Graph No. 3 shows the increase in concentration of extracted salts as the water added to the same quantity soil is decreased. The curve has been extended with cross lines and suggests when the soil contains about 10 per cent. moisture (field trials were planted and germinated well at Merredin at a moisture content of 10-12 per cent.) the salts not held by soil colloids, etc., would amount to 700 parts per million in solution. A continuation of the curves on graph 2 strongly indicates that at about 600 parts per million the copper dusts would be insoluble at temperatures of 30-33° C.

The maximum solubility of B.S. in H_2CO_3 is 112 parts per million of copper at 15°C. and at 30-33°C. 77.5 parts. Allowing for lower temperatures in the field at the time of planting the copper dissolved will not be sufficient for a lethal solution. E. E. Free has observed the falling off in the solubility of basic copper carbonate in H_2CO_3 when certain ions are present. The soluble salts in the Merredin loam (top 2in.) are normal for the soil type and are by no means excessive; they are, however, slightly higher in the sand. The soils are totally different. Graph No. 4 shows the variations in the soluble salts in the first two inches of Merredin loam, together with lines representing the mean soluble salts of both types. A sample was taken daily in 1928 for 20 days from different portions of the fungicide plots. The figures have been calculated to a dry soil basis. The original intention was to determine the solubilities of the dusts in soil extracts and see whether variations in the water soluble salts so affected the solution of the copper as to account for the variations in the counts in separate treatment rows.

The work of S. U. Pickering, C. T. Gimingham and B. T. P. Barker and C. T. Gimingham on the fungicidal actions of Bordeaux mixtures was only brought under the author's notice in December, 1931, after most of the experimental work had been done and definite conclusions drawn supporting almost entirely the views of Barker and Gimingham.

Pickering has studied the solubilities of various Bordeaux preparations in H_2CO_3 and made the observation that a dried out mixture is not as soluble as a freshly prepared one, which accounts for the low solubility of sample B.S. compared with some of his freshly prepared compounds. He gives the following equation:—

1. $10CuO.\ 2.5SO_3 + 3.75CO_2 = 3.75\ (CuO)_2\ CO_2 + 2.5CuSO_4$

which is better written,

1a. $2[CuSO_4.3Cu(OH)_2] + 3CO_2 \rightleftarrows 2CuSO_4 + 3[CuCO_3.Cu(OH)_2] + 3H_2O.$

The reaction is reversible and would only proceed to completion on extreme dilution with H_2CO_3. The forward action depends on the CO_2 present. $CuSO_4$ reacts with $CuCO_3.Cu(OH)_2$: liberating CO_2. On passing CO_2 into a suspension of $CuSO_4.3Cu(OH)_2$ some Cu immediately passes into solution. The basic sulphate changes from a blue to a green colour in about 24 hours whether the CO_2 is passed continuously or the saturated suspension kept in a stoppered flask. On stopping the passage of the gas and exposing the suspension to the air, the dissolved Cu and SO_4 are precipitated in a few hours while the suspended material remains green. A little CO_2 is permanently absorbed by the basic sulphate.

Returning to the germinating grain of wheat in the moist seed bed. The ratio of water absorbed to the copper dust is $\frac{\cdot 047}{\cdot 0000924}$, *i.e.*, approximately 500 to 1. The solubility tests were carried out at the ratio 25/.05,

i.e., 500 to 1. At this proportion 224 parts of B.S. (50 per cent. Cu content) were soluble in one million parts of H_2CO_3 at 15° C. Neglecting any Cu dissolved as carbonate in the above equation the extent to which the forward reaction has taken place can be calculated.

At a 1-500 dilution the actual Cu dissolved from .05 gm. of B.S. is 0.0028 gm., *i.e.*, 11.2 per cent. of the copper contained in it on the assumption that B.S. contains 50 per cent. Cu (actually the percentage is 52). At a 1-500 dilution the reaction will therefore reach equilibrium when 11.2 per cent. of the copper in the basic sulphate (containing 55 per cent. Cu) has dissolved, *i.e.*, 45 per cent of its contained $CuSO_4$ has been liberated. At this dilution the reaction has proceeded 45 per cent. of its way. This conclusion supports Pickering's contention that the dried out dusts are less soluble. Except with extreme dilution samples D25, E25 and B.S. will not dissolve completely, due to the formation of the very insoluble basic carbonate. Pickering again shows theoretically that Bordeaux mixtures prepared with different proportions of lime give basic sulphates of different composition. He argues that $10CuO,SO_3$ would give less soluble copper than $4CuO,SO_3$ and correctly so, but on treatment with H_2CO_3 more copper appears in solution than is expected. This can only be due to the solubility of the basic carbonate formed. Once the liquid spray has dried out its solubility falls, undoubtedly due to change in particle size.

Free when investigating the solubility of freshly prepared basic carbonates found their initial solubilities in H_2CO_3 varied from 57 to 107 parts per million, but by treating a suspension of the material with the gas for several days he prepared a product which gave a solubility of approximately 35 parts per million of Cu in water saturated with CO_2. He found that the addition of certain substances to the solvent affected the solubility of the basic carbonate, *e.g.*, sodium chloride increased the solubility slightly while sodium carbonate and calcium carbonate decreased it. C. A. Seyler's explanation of this phenomenon is a satisfactory one—the basic carbonate dissolved as bicarbonate.

$$CuCO_3.Cu(OH)_2 + 3H_2CO_3 \rightarrow 2H_2O + 2Cu(HCO_3)_2$$

and at equilibrium

$$\frac{[Cu]^2\ [HCO_3]^4}{H_2CO_3} = K$$

The addition of Cu or HCO_3 ions will therefore decrease the solubility of the Cu. This explanation may be applied to the depression of the solubility of the copper dusts in the soil solution which contains the ions Cl, HCO_3, SO_4 and NO_3 only in quantity. It can be definitely stated that Pickering's contention that the copper in sprays is rendered sufficiently soluble by CO_2 to be toxic to fungi on plants is untenable when applied to copper dusting powders on wheat grains germinating in the soil. The hydrogen ion concentration of the soil solution, too, would have an important bearing on the solubilities of the dusts.

Dismissing the CO_2 solubility theory the only other explanations for the solubility are as follows:—

1. Solution in a secretion of the spores.
2. Decomposition products of the germinating grain other than carbon dioxide.
3. Contact with injured portions of the grain.

D. DETERMINATION OF SPECIFIC CHEMICAL AND PHYSICAL CHARACTERISTICS.

Mackie and Briggs suggested the apparent density for differentiating between copper dusts of uniform chemical compositions but diffierent fungicidal properties. Unfortunately their work is based on only four samples tried out in the field for one season. Their standards have been arrived at by averaging the analyses of twelve basic carbonates selected from a series of twenty samples. Some of the densities of the selected twelve are given and of these, two only reach the required density. Experience in Western Australia and Victoria shows that some high density compounds are better than low density ones. In view of this fact it is highly probable that had Mackie and Briggs tried out all their samples in the field they would have looked for some other property in their dusts which could have been associated with bunt control. Apparent density cannot be correlated with particle size unless the particles are themselves uniform in size—the small particles will fill the spaces between the larger ones and so increase the density.

A rock sample was broken in a crusher and the material sifted through a series of I.M.M. sieves. The apparent densities of the fractions were determined with and without tamping. Quantities of material were added at intervals to a 50 ml. cylinder and tamped down on a wooden bench covered with a cloth; the maximum amount of material that would occupy 30 mls. volume was weighed. The other densities were determined by pouring a quantity of material into a 2½in. funnel without a stem and supported one-half an inch above a cut-down cylinder of 30 mls. capacity. The uneven surface was struck off and the contents weighed. Good duplicate results were obtained.

Apparent Density of Samples.

Mesh.	Without tamping.	With tamping.
20–30	1·220	1·403
30–60	1·140	1·377
40–120	1·062	1·327
120–200	1·008	1·298
<200	0·724	1·256

It is clear from these figures that with particles of uniform size the apparent density decreased with a decrease in particle size.

Increasing amounts of the finest material were then added to the coarsest material and the apparent densities of the mixtures determined.

APPARENT DENSITIES OF MIXED MATERIAL.

Proportions of coarse to fine material by weight.		Without tamping.	With tamping.
Coarse	<200		
100	20	1·232	1·572
100	40	1·233	1·680
100	60	1·144	1·708
100	80	1·109	1·696

The specific gravities of the coarse and fine materials were 2.53 and 2.60 respectively. Without tamping the "lightening" effect of the fine particles

on the apparent density of the coarse ones does not make itself felt until the mixture contains about 30 per cent. of fine particles; below this figure the value is increased. With tamping the maximum apparent density is obtained when the mixture contains about 40 per cent. of fine material; the value then begins to fall. There is no reason why this phenomenon should not make itself apparent in mixtures of copper dusting powders in which the particles may range in size from 200 mesh to a 1,000 mesh or smaller. It is possible that to get comparative results the amount of tamping should be governed by the mechanical composition of the powders.

Mackie and Briggs determined densities "by shaking down a given weight in a measured cylinder," neither quantities nor the amount of shaking being specified. Chemists have interpreted these instructions according to their own ideas. The densities in this report have been determined by tamping down one ounce of material in a 50 ml. cylinder until the volume is constant. Twentyman has evolved a satisfactory method in which the conditions have been standardised.

Table 6 gives the results obtained with three samples of basic carbonate of varying densities during the year 1928 only.

TABLE 6.

Spore dosage 10–750—Variety of wheat *Booran*.

Sample ... ... Density	B 25 58·7		B 27 53·8		A B 49·0	
	Loam.	Sand.	Loam.	Sand.	Loam.	Sand.
Per cent. bunted plants ...	33	3	51	7	57	12
Per cent. infection controls	83	91	83	91	83	91

It will be seen that those samples recording high densities are better in practice than the low densities under the conditions of these experiments. The evidence is not complete and it is not suggested that other basic carbonates would behave in the same way. In fact other investigators show that light powders are better than heavy ones. The inference is that density determinations do not necessarily divide good from bad commercal powders.

Difficulty arises in distinguishing between those powders which contain varying proportions of basic carbonate and basic sulphate, as the true specific gravities differ. The oxychlorides complicate the position still further. Twentyman's figures when graphed do not show uniformity in relation to bunt control; the graph for all samples fluctuates, while separate graphs of the basic carbonates, basic sulphates and mixtures follow the same form.

While it is admitted apparent densities are a measure of fineness when the particle size is uniform or particles of similar size predominate, the fact remains that only in some cases do densities foretell how powders will behave in field trials.

Sample AB was supplied by the manufacturers and was stated by them to have an apparent density of 30.5 lbs. per cubic foot. A known weight of this powder was tamped down in a 50 ml. cylinder until a volume was obtained giving a density value of 30.5 lbs. per cubic foot. The same quantity of B25 was tamped under exactly the same conditions and gave a value of 34.1. B25 has given better results in the field than AB. By tamping

to a minimum volume, *i.e.*, maximum apparent density, the figures were:— AB 49 and B25 58.7. Twentyman obtained a value 33.5 for the brand AB by his method but whether the two samples were similar is of course unknown. However repeating the above determinations by tamping AB to 33.5 the B25 figure became 39.9. Twentyman has been good enough to determine the density of sample A27 for the author and obtained the figure 54 lbs. per cubic foot; he points out that the result is a close approximation as only an ounce of material was sent to him. A27 tamped right down went 89 lbs. As will be seen from Tables 2 and 3 this material gave good results in trials. Whether densities are determined with controlled or maximum tamping a relationship exists between the figures obtained, *i.e.,* the West Australian figures may be compared with those of other investigators.

FINENESS.

The results of field trials particularly with the basic sulphates suggest that the powders can be too fine. Sample BS is a very coarse dust while E25 is very fine, the former is by far the better bunticide, and has a lower apparent density. The low apparent density is ascribed to the scarcity of small particles to fill the spaces between the larger ones. Again the difference may be due to the different chemical compositions or the hardness of the particles. Some coarse particles in both dusts, particularly B.S., have a spongy appearance and may present a greater surface to solvents exuded by the bunt spores.

In 1929 an attempt was made to separate the finest fraction from the coarse ones with a stream of air. The apparatus was not designed for quantitative determinations. Coarse sand was added to the powders to facilitate agitation under constant air pressure. The fine and coarse materals were used in field trials together with sample B.S.

TABLE 7.

Rate of infection 10–750, *Gluyas Early* wheat. Planted in Merredin loam.

	Per cent. bunted plants. 1929.	Per cent. bunted plants. 1931.
Average controls	41·6	8·6
B25 original	12·4	0·0
B25 fine	9·4	1·7
B25 coarse	7·2	1·2
D25 original	4·4	0·9
D25 fine	5·4	0·9
D25 coarse	10·2	0·3
AB fine	5·2	2·1
AB coarse	4·0	1·5
B.S. original	2·2	0·7
Booran wheat—		
Infected 10–750	67·0	

The 1929 trials did not give the results expected, in fact no significant information can be gathered from them, while the 1931 figures complicate the position still further. Planting in 1931 was completed on 11th June and was followed by dry conditions with extremely low temperatures. Sixteen frosts were recorded during the remainder of the month, on one occasion the terrestrial minimum was as low as 20.7° F. The low bunt infection associated with cold conditions and slow germination of the wheat is a point of

significance when comparing one season's results with others. In 1929 the coarse and fine fractions of AB gave better results than those of B25 and *vice versa* in 1931. D25 and B.S. still maintain their superiority.

The use of the 200-mesh sieve as a test for fineness is the subject of much controversy. It is the finest sieve in general use in most laboratories and appears to be a good one to separate ineffective lumps from fine material and insure at least a dust is supplied to farmers.

EFFECT OF CARBON DIOXIDE ON THE MOISTENED DUSTS.

Weighed quantities of six of the dusts were spread out on moistened filter papers and placed in an atmosphere of moist carbon for eight days. The papers were allowed to air dry and the absorbed carbon dioxide determined. The increases were as follows:—

Sample	AB.	B25.	F25.	D25.	B.S.	E25.
Absorbed CO_2 per cent.	0.28	2.36	0.65	0.40	3.54	0.84

Sample D25 had a distinctly blue colour while B.S. was muddy blue. All samples turned to a bright green after a few days contact with the carbon dioxide and retained their new colours on drying.

COLOUR.

The majority of the commercial copper dusting powders are green in colour. Sample D25 which has given consistently good results has a distinctly bluish green colour. It would appear that colour has no relationship to fungicidal properties.

SUMMARY.

Field trials have been conducted with commercial "copper carbonates" over a period of years in different soils with a view to fixing standards for these materials.

Beyond the fact that the compounds should contain approximately 50 per cent. of copper and be reasonably fine, no constant physical or chemical characteristic could be found which would distinguish a good powder from a bad one. Generally speaking basic copper sulphates and mixtures of basic sulphates and carbonates have proved better bunticides than the basic carbonates or oxychlorides tested.

The Merredin loam soil solution depresses the solubility of the copper powders in carbonic acid derived from the germinating grain to below a lethal dose.

The amount of powder actually held on the dusted grain is not a measure of the efficiency of the powder.

The apparent density test is not a reliable one for indicating bunticidal properties.

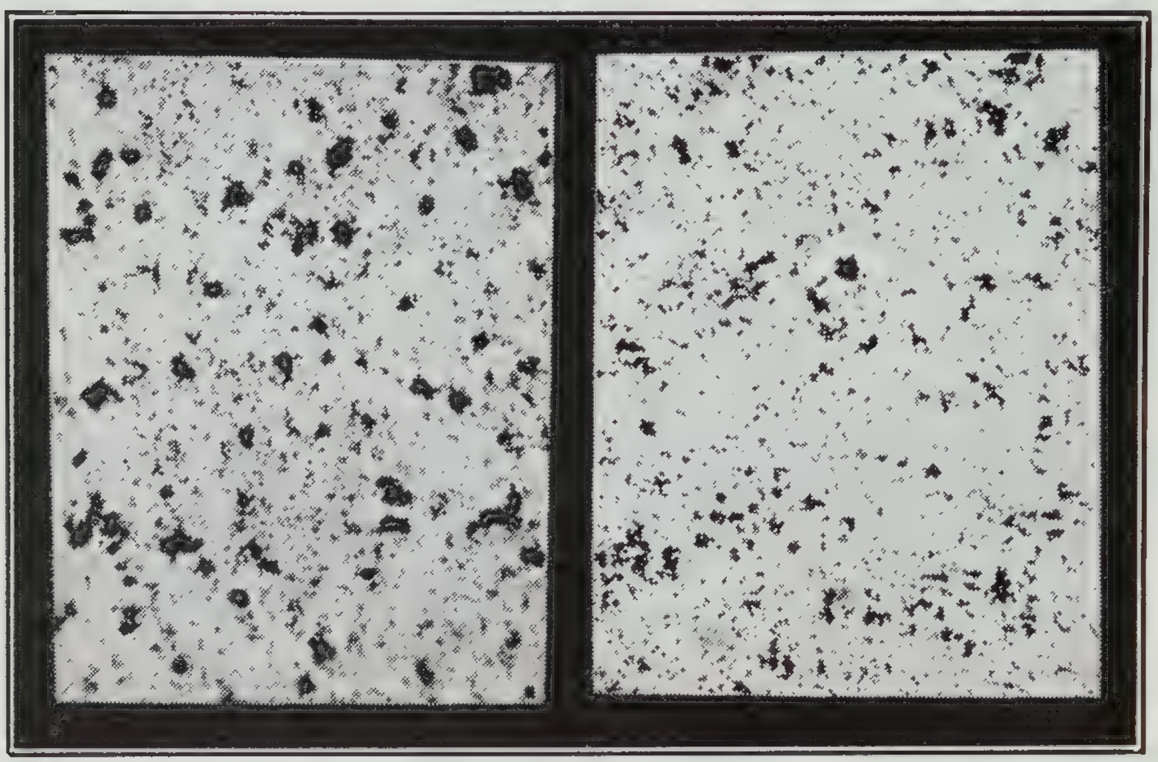
STANDARDS.

The following standards are recommended for commercal "copper carbonate" powders:—

(a) They shall contain not less than 50 per cent. of copper in the form of basic carbonate, basic sulphate, mixtures of these compounds, or oxychlorides.

(b) 98 per cent. of each powder should pass through a 200-mesh I.M.M. sieve when shaken with water and washed with a gentle stream of water.

(c) Water soluble copper should not be present.



B 8. B 25.

Glycerine dispersion. × 70.

Microphotographs of dusting powders.

ACKNOWLEDGMENTS.

The chemical work in this investigation has been carried out in the Government Chemical Laboratory, Perth, and the author would like to express appreciation for the manner in which the field trials have been carried out by Mr. E. J. Limbourn, cerealist at the Merredin Experiment Farm, and Mr. D. R. Bateman at Chapman; detailed reports from these officers have materially assisted the preparation of the paper. The author thanks Mr. E. C. Atkins, junior, for the use of a block of land at Applecross, and Dr. E. S. Simpson, Government Mineralogist and Analyst, for permission to publish these results.

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10.—AN ECOLOGICAL ANALYSIS OF THE PLANT COMMUNITIES OF THE "JARRAH" REGION OCCURRING ON A SMALL AREA NEAR DARLINGTON.

With Special Reference to the Indicator Value of Species.

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In a paper on "The geology and physiography of parts of the Darling Range near Perth" (2) E. de C. Clarke and F. A. Williams state that they made use of the predominance of a white-barked eucalypt (*E. redunca* var. *elata*) as an indicator of the presence of epidiorite dykes. The original purpose of the present investigation was to verify this observation and to see if there were any reliable indicator plants among the shrub species.

As the work proceeded, however, it was found that interest in the plant communities increased considerably and that the determination of indicator value tended to become more or less subordinate. In this paper an attempt has been made to analyse, by means of quantitative field methods, the composition of the valley vegetation and to compare it with the adjacent vegetation of the hill-tops. Emphasis has also been laid on the correlation between the vegetation units and the more obvious soil-types as derived from the geological formations.

It was decided that the best method of approach to the problem was that of taking a representative area and working out the details as accurately and fully as time would permit. In the choice, care was taken to avoid subseral areas produced by fire and at the same time to have represented all the main soil-types of the Darlington Area. The area finally chosen is included in the University Geology Department's survey of the Darlington Area, and this in turn falls just within the northern limits of the "Jarrah" Region (1, p. 121) and in what Gardner has termed the "Marginal Forest of the Plateau" (4).

METHODS OF WORK.

The area studied was first covered by an accurate topographic survey (by the method of tacheometry) and the positions of most of the trees were determined as the work progressed. The mapping of the trees on the laterite and other places where they were more than ordinarily numerous was done by a modified quadrat system; index trees being previously surveyed with the theodolite. There is still an area in the south-east corner which is incomplete (see map); its similarity to adjacent areas of the gravel slope does not seem to justify the extra work that would be entailed.

The geology and soil-types were next mapped in, the former being determined by outcrops and surface indications.

In order to analyse the shrub vegetation the area was divided into chain-square areas from the centres of which six foot square sample areas were taken. From each of these a composition list was compiled, only annuals and some rare under-shrubs being omitted (5).

The only measurements of habitat factors, apart from those which may be deduced from the survey, were those on the evaporating power of the air. White Livingston Atmometer Cups were set up in the field; one under the "Jarrah" canopy near the south boundary, and one just above the 650-foot contour near the centre of the south-west boundary (see Plate VIII.). A black cup was also used in conjunction with these to obtain an approximate comparison for the total light received at the two stations.

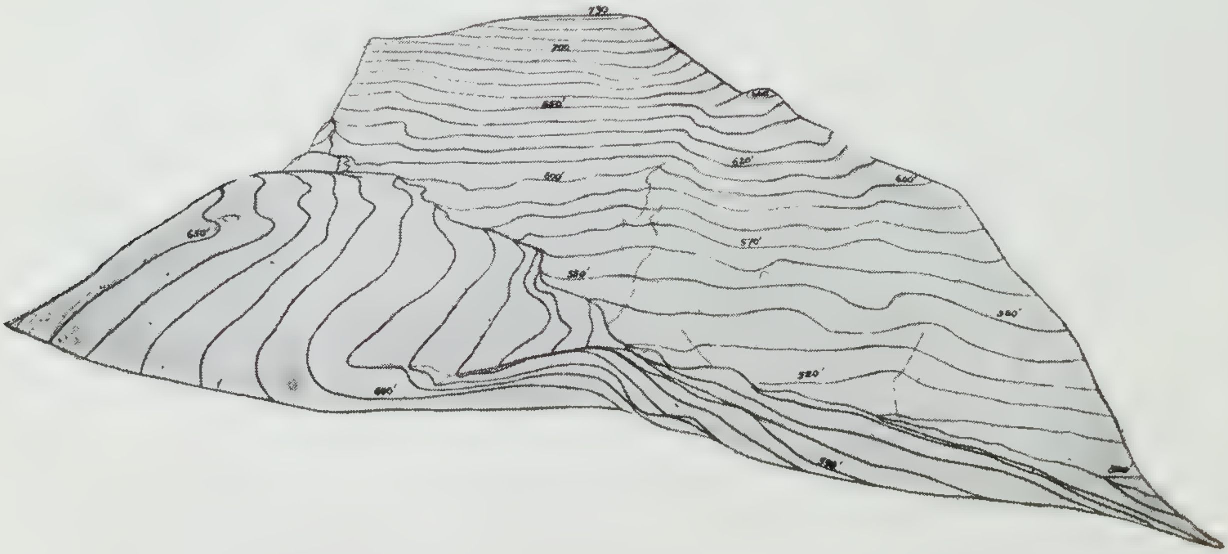
TOPOGRAPHY.*

"The western part," of the "Jarrah" region, "is the dissected western margin of the Great Plateau of Western Australia (Jutson, 1914, p. 19) (3) bounded on the west by the Darling Fault. The topography near the fault-line scarp is somewhat rugged, passing in a distance of five miles or so to the east into the more gently undulating contours of the eastern part of the region." (1, p. 121.)

The Darlington Area "lies in the valley of the Helena River, one of the westerly flowing streams which according to Jutson (1914, p. 128) were consequent on the formation of the Darling Fault, and which, having steeper courses, were able to capture and dismember the senile North-South drainage" (2).

Cohen Brook, which traverses the area from south-east to north-west, is one of the rejuvenated tributaries of the Helena River which "flow in their upper parts through wide shallow valleys in the laterite-covered Darling Peneplain, but on reaching the slopes of the Helena valley they have the same character as the wholly immature tributaries" (2). Beyond the north-west corner of the area Cohen Brook takes a bend and plunges down the steep rejuvenated part of its course.

The topographical details of the area are best seen from the perspective elevation (Text Fig. 1); further description is unnecessary, especially as no detailed work was done on the effect of aspect. In the figure the vertical scale is twice that of the horizonal—the slope angles are therefore accentuated. (N.B.—The absolute elevations were not determined but the approximate figures are given on the figure.)



Text Fig. 1.

Physiographic Perspective Elevation from North Boundary looking South.

Photo., H. Smith.

* See Plate VIII. for detail.

GEOLOGY.*

The Darlington Area is essentially composed of massive granite rocks. They "are traversed by a great number of epidiorite dykes varying in width from a fraction of an inch to a chain or more, and traceable in some instances for more than a mile along their strike." "There is little difficulty in mapping them fairly accurately in the steeper parts of the area; they can in many places be seen outcropping for many chains, and in the intervals their courses are indicated by the abundance of epidiorite boulders, by the dark red soil, and by the predominance of a white-barked eucalypt which contrasts strongly with the dark trunks of the 'Marri' and 'Jarrah' (?)† which predominate on granite" (2).

In only a few places does the Darling Area rise to the "laterite level," which in this region lies between 600 and 700 feet above sea-level.

SOIL-TYPES.*

The soil-types recognised are primarily those in direct relation to and derived from the underlying rock. The author is aware that in many cases such a relation would not necessarily hold good, but superficial examination of the soils in question seemed to indicate its validity on the area studied.

The gravel slide is exceptional but it can scarcely be termed a soil-type. It consists of fragmented laterite which has been washed down over the upper slopes of the valley, thus obscuring the granite and the epidiorite. The amount of gravel varies with the distance from the laterite and the area it covers is best considered to be transitional in nature.

CLIMATIC FACTORS.

The annual rainfall at the nearest meteorological station, Kalamunda, which is two miles south of the area, averages 43 inches. Table 1 gives the mean monthly rainfall, the monthly rainfall from December 1930 to November 1931, and the mean maximum and minimum temperatures over the same period:—

TABLE 1.

Meteorological Information for Kalamunda.

(From *Journal of Agriculture*, W.A.)

Mean Annual Rainfall ... ... 43·26 inches
December, 1930, to November, 1931 ... 48·95 inches

Rainfall.	Dec., 1930.	Jan., 1931.	Feb., 1931.	Mar., 1931.	Apl., 1931.	May, 1931.	June, 1931.	July, 1931.	Aug., 1931.	Sept., 1931.	Oct., 1931.	Nov., 1931.
Mean monthly...	0·81″	0·55″	0·65″	0·85″	1·89″	6·04″	8·30″	8·45″	6·81″	4·69″	3·15″	1·07″
1930–1931 ...	1·68″	0·00″	0·03″	0·83″	3·60″	7·05″	7·47″	11·1″	7·91″	7·52″	1·70″	0·02″
Temperature—Mean maximum	80·5°	87·3°	82·3°	82·7°	73·0°	63·1°	58·2°	57·5°	59·8°	60·7°	70·8°	78·8°
Mean Minimum	56·8°	60·4°	57·5°	60·0°	55·2°	47·8°	43·5°	47·3°	46·3°	46·8°	51·5°	52·6°

Evaporating Power of the Air:—Standardised spherical atmometer cups were set up in the field as stated above for two periods of two weeks. The detailed results appear in Table 2.

* See Plate VIII. for detail. † Question Mark mine.

TABLE 2.

First Period—

Saturday, October 10th to Saturday, October 24th:

Mean maximum temperature	...	77·3
Mean minimum temperature	...	53·2

Second Period—

Saturday, October 31st to Saturday, November 14th:

Mean maximum temperature	...	79·6
Mean minimum temperature	...	54·6

N.B.—A few points more rain and less wind than there were in the first period.

Readings (standardised).

Atmometer.	Period.	Open Marri Consociation.	Closed Jarrah Association.
White Bulb	First ...	353 grams	388 grams
	Second...	314 grams	326 grams
Black Bulb	First ...	566 grams	—— ——
	Second...	—— ——	416 grams
Excess of Black over White Bulb reading	First ...	213 grams	—— ——
	Second ...	—— ——... ...	90 grams
Approximate ratio of total radiant energy received		7 :	3

Quite unexpectedly it was found that evaporation under the closed "Jarrah" Association was more intense than in the open "Marri" Consociation. This no doubt is to be attributed to the difference in severity of the east winds at the respective stations.

If the excess of the black bulb measurement over that of the white is to be taken as an approximate measure of the radiant energy received at the stations, and if the two periods are considered reasonably comparable, then the ratio for this factor is approximately 7 : 3. Recent research on the light factor in forest ecology suggests that in this case it would be far outweighed by the effect of competition.

It was unfortunate that atmometric readings could not be extended over the entire year. At present there is no basis for comparison either between seasons or with other localities in Western Australia.

VEGETATION.

Two Plant Associations have been recognised on the area studied; the *Eucalyptus calophylla—E. redunca Association* which almost exclusively constitutes the valley vegetation of the "Darlington Area," and the *Eucalyptus marginata Association* which dominates the laterite-covered Darling Peneplain. The following descriptions of the Plant Associations and their subdivisions are based almost entirely upon the map (Plate VIII.) and the vegetation analyses (Tables 3 and 4). Discussion of the developmental relations between the communities will be found in a later section of the paper.

It should be emphasised that the description of the *E. marginata Association* here given, only applies to a fringe of the "prime Jarrah forest"

and that it is based on much less evidence than is the description of the *E. calophylla—E. redunca Association.* Unfortunately no ecological details of the "prime Jarrah forest" have yet been published.

Eucalyptus calophylla-E. redunca Association. (Plate VII., Figs. 1 and 3.)

This Association occupies nearly three-quarters of the area and is characteristic of the soils derived from granite and epidiorite. It also occupies most of the lower parts of the gravel slide. The only associated tree species are *Eucalyptus accedens, Nuytsia floribunda,* and *Dryandra floribunda.* The latter, however, is not at all typical of this Association and may possibly have developed after a bush-fire. In another part of Darlington *D. floribunda* has taken possession of a deserted vineyard to the exclusion of almost all other species.

E. calophylla (Marri) and *E. redunca* (Wandoo) are present in approximately equal numbers and form an open woodland, there being on an average four trees to the square chain. *E. accedens* is only represented by one specimen on the area studied; elsewhere it was observed on high ridges and usually associated with *E. marginata.*

Xanthorrhoea Preissii with its peculiar grass-tree habit is characteristic of the Association, there being about 25 and often as many as 40 specimens to a square chain.

The cycad, *Macrozamia Reidlei* is less common, and, though constantly present, apparently favours the moister and shadier localities.

The shrub stratum of the Association has an average height of from one and a half to two feet and is of a markedly sclerophyllous type. The most constant members are *Hibbertia hypericoides, Acacia pulchella, Hibbertia montana,* and *Dryandra nivea,* and of these the first two constitute co-dominants of the stratum.

Of the larger shrubs (4 to 5 ft.) the following are fairly abundant:—*Hakea cristata, Hakea trifurcata,* and *Daviesia horrida.*

In Table 4, in which a full analysis of the shrub vegetation is given, the figures represent constancy, not frequency, and, for comparison, are in each case reduced to a basis in which 10 represents 100 per cent. constancy.

The quadrat (Plate VI., Fig. 3) which is a fairly typical example of the ground vegetation of this Association, indicates the spatial relations of the individual plants of the stratum and also affords a type example of their frequency.

The frequencies of the less common species of the Association as a whole are to a large extent reflected by their constancy figures (Table 4).

Eucalyptus calophylla Consociation.

This characterises soils derived from granite and is also developed in patches along the creek bed, where moisture conditions are better and the soil is deeper. *E. redunca* is occasionally present and a large proportion of the *Nuytsias* are also associated.

Eucalyptus redunca Consociation.

This characterises soils derived from epidiorite, even where the latter is partially obscured by the gravel wash. There are no associated trees.

Dryandra floribunda Society.

This Society occupies about three square chains of very rocky granitic soil towards the west boundary of the area (see map). Its presence is abnormal for the Association and it may have developed after a severe bushfire.

Nuytsia floribunda can scarcely be said to form definite societies though it occurs in more or less isolated areas. It is usually associated with pure "Marri" or with the mixed "Marri"-"Wandoo" community and occasionally extends into the "Jarrah" Association where the two Associations meet. Nuytsia is rarely if ever found as a constituent of the "Wandoo" Consociation and does not upset the space relations of the communities in which it occurs.

With regard to the spacing of the trees within the Association (see Table 3) it should be noticed that the two Consociations are almost the same, namely, three trees per square chain, and that this is considerably less than for the mixed part of the Association which has 4.5 trees per square chain.

Eucalyptus marginata Association. (Plate VII., Fig. 2.)

This Association covers the remainder of the area and characterises the laterite and the upper parts of the gravel slide. Towards the northern boundary there are three small areas (15 square chains in all) which are developed on what is apparently purely granitic soil. The significance of these exceptions will be discussed later.

Associated with the Jarrah (*E. marginata*) in this area, there is a large proportion of *E. calophylla* and *E. redunca,* the percentage being considerably greater than is normal.

Casuarina Fraseriana is the only other tree species found on the area, though *Dryandra floribunda* occurs a little to the south. The distribution of *Nuytsia floribunda* has already been discussed.

The shrub stratum is more scanty than in the other Association and there are spaces between the shrubs which are covered with a litter of leaves. The more important species are—*Bossiaea ornata, Grevillea synapheae, Hibbertia hypericoides, Leschenaultia biloba, Hovea chorizemifolia, and Dryandra nivea.*

Xanthorrhoea and *Macrozamia* though present, are not so plentiful as in the *E. calophylla-E. redunca Association.*

The quadrat (Plate VI., Fig. 1) is typical of the laterite ground vegetation here considered. Although the number of specimens per unit area is comparable with that for the *E. calophylla-E. redunca Association,* the individual specimens are on the average only about half the size; hence the comparative scantiness of the covering.

Casuarina Fraseriana Society.

This occupies about three square chains of the lateritic area and is almost a pure stand of "sheoak." Of the 41 trees present only six are eucalypts.

It may be found, as the result of further investigation, that the *E. marginata Association* as developed on the gravel slide is best considered as an ecotone or belt of transition between the *E. marginata Association* on the laterite and the *E. calophylla-E. redunca Association* in the valleys. The shrub stratum of the upper parts of the gravel slide was not included in the shrub analysis.

INDICATOR VALUE.

COMMUNITIES.

The correlation between soil and the major plant communities have been stated in the descriptions of the latter. These were primarily based on an extended compass survey and upon general observations throughout the Darlington Area. The correlation between the *E. marginata Association* and soils derived from laterite would certainly be open to question if based solely upon the map (Plate VIII.) but would be undoubted if a vegetation map of the entire Darlington Area were available. Similarly the agreement between the *E. redunca* and *E. calophylla Consociations* and the epidiorite and granite respectively was confirmed and emphasised by the extended observations.

TREE SPECIES.

Turning now to the consideration of the individual tree species it is found that the correlation with soil type is not nearly so precise as that for the communities. The following specific statements are based on Table 3.

Eucalyptus calophylla, R.Br.

The "Marri," locally called "Red Gum," is present on all the soil types. On granite it constitutes 60 per cent. of the Eucalypts and on the gravel slide it shares the dominance with *E. redunca,* the two species being present in equal numbers. On epidiorite and laterite *E. calophylla* is subordinate to the other Eucalypts.

The percentages shown opposite "Gravel slide over granite" and "Gravel slide over epidiorite" are for those portions of the gravel slide which do not support the *E. marginata Association.* The figures show that the correlation is not destroyed by the presence of the gravel.

Eucalyptus redunca, Schau. var. *elata.*

The "Wandoo," erroneously called "White Gum," is dominant on epidiorite (70 per cent.), co-dominant with *E. calophylla* on the gravel slide (37 per cent.), and subordinate on granite and laterite.

Eucalyptus marginata, Sm.

The "Jarrah" tree dominates the laterite (79 per cent.), is very frequent on the gravel slide (26 per cent.), and is normally absent from granite and epidiorite. The high percentage (26 per cent.) here found on granite is due to the presence of the abnormal remnants of the *E. marginata Association.*

Nuytsia floribunda (Labill.), R.Br.

This species is, on the area studied, confined to granite and the lower parts of the gravel slide. As yet the author has not seen a specimen on laterite or on any purely epidioritic soils.

Casuarina Fraseriana, Miq.

This "Sheoak" is, in the Darlington Area, definitely confined to laterite.

Dryandra floribunda, R.Br.

This species, though present on granite on the area studied, is normally found on laterite. Given the chance, it rapidly colonises abandoned cultivations and severely burnt areas, irrespective, it would seem, of the soil type.

Xanthorrhoea Preissii Endl. and *Macrozamia Reidlei* (Gaud.) Gardner are present on all the soil types. Nothing definite can as yet be said as to the causes of their variable frequency from place to place.

SHRUB SPECIES.

The details of the shrub analysis appear in Table 4, and are based on 197 sample areas obtained as described under Methods of Work. The number of samples for granite (66), epidiorite (35), and laterite (20) are

as complete as the area would permit. In the case of the gravel slide it was decided to analyse a limited number only, as the area covered by this is proportionally greater than is the case for the Darlington Area as a whole. The upper portion of the gravel slide, which more or less coincides with the transition between the laterite and valley vegetation, was entirely omitted from the analysis.

In taking the samples, areas which were obviously developmental were omitted, and in order to eliminate some late seral stages which were unavoidably included, the whole series was subjected to an analysis based on the dominant and highly constant species. First the composition lists were arranged in groups each possessing the same constant species. For instance in one group *Acacia pulchella, Hibbertia hypericoides* and *Dryandra nivea* were present and *Hibbertia montana* absent; in another *Acacia pulchella* and *Dryandra nivea* were absent and the two *Hibbertias* were present. The constancy figures for all these groups were then compared with those for the whole Association. By this means, those groups which lacked either or both of the dominants, and showed other marked divergence from the average type, were discarded from the final analysis. It was soon seen that there were no fundamental distinctions between the shrub stratum covering the granite, epidiorite, or lower parts of the gravel slide. In other words, the dominants were the same and the more constant species showed almost equal constancy in each case.

In the shrub analysis table, column "A" is obtained by the summation of columns "D," "E," and "F." Column "A" is therefore, for the area studied, a fairly accurate analysis of the shrub stratum of the *E. calophylla—E. redunca Association.* For comparative purposes the figures are reduced to a basis of ten, and in this instance are expressed to the first decimal place.

Column "C" affords the striking contrast which might be expected between the shrub vegetation of the two Associations (compare columns "A" and "C"). Column "B" represents the ground vegetation of the *E. marginata Association* as developed on granite and shows a composition intermediate between the two normal Associations.

The following classification of the shrub species is based directly on Table 4, and presents the main features of the Table in a more lucid form.

1. Species whose constancies are approximately equal for granite, epidiorite, gravel slide, and laterite.

Dryandra nivea	*Hibbertia hypericoides*
Hovea trisperma	*Hibbertia montana*
Hakea bipinnatifida	*Olearia paucidentata*
Sphaerolobium medium	*Gompholobium marginatum?**

*Probably overlooked on gravel (see Table).

2. Species whose constancies are approximately equal for granite, epidiorite, and gravel slide, but which are absent from or relatively rare on laterite.

Acacia pulchella	*Leucopogon sprengelioides*
Grevillea pilulifera	*Hypocalymma angustifolia*
Hakea undulata	*Casuarina humilis*
Hakea trifurcata	*Daviesia polyphylla*
Andersonia sprengelioides	*Bossiaea biloba*
Thomasia glutinosa	*Daviesia horrida*
Hibbertia polystachya	*Astroloma pallidum**
*Baeckea camphorosmae**	

*Rare on laterite.

3. Species whose constancies indicate that they are practically confined to granite.

Dryandra armata | *Gompholobium polymorphum*
Hakea stenocarpa

4. Species whose constancies indicate a more or less marked preference for granite as opposed to epidiorite. Constancies various on gravel slide—absent from laterite.

Synaphaea acutiloba | *Melaleuca scabra*
Eriostemon spicatum | *Hakea incrassata*
Gastrolobium epacridioides | *Chorizema Dicksonii*
Pultenaea ericifolia | *Petropohila striata**

*Also on laterite.

5. Species whose constancies indicate a more or less marked preference for epidiorite as opposed to granite; absent from laterite.

Daviesia brevifolia | *Petrophila seminuda*
Hakea erinacea | *Phyllanthus calcycinus*
Isopogon asper | *Trymalium ledifolium*
Synaphaea pinnata | *Acacia decipiens*

6. Species confined to laterite (excluding the remnant of *E. marginata Association* on granite).

Bossiaea ornata | *Leschenaultia biloba*
Grevillea synapheae | *Conostylis setigera* var. *discolor.*
Adenanthos barbigera | *Isopogon sphaerocephalus*
Hibbertia pachyrrhiza | *Styphelia tenuiflora*
Kennedya coccinea
Hovea chorizemifolia

N.B.—Some of these species may occur on the upper parts of the gravel slide.

7. Species whose constancies indicate a preference for laterite.

Synaphaea petiolaris | *Daviesia pectinata*
Dampiera linearis

8. Species whose constancies indicate a preference for gravel.

Oxylobium cuneatum | *Dillwynia cinerascens.*
Dampiera alata

9. Species whose constancies are equal for granite and epidiorite—absent or infrequent on gravel and laterite.

Pimelea rosea | *Grevillea bipinnatifida*
*Tetratheca hirsuta**

*Assuming the form of *T. hirsuta* found on laterite to be a distinct variety.

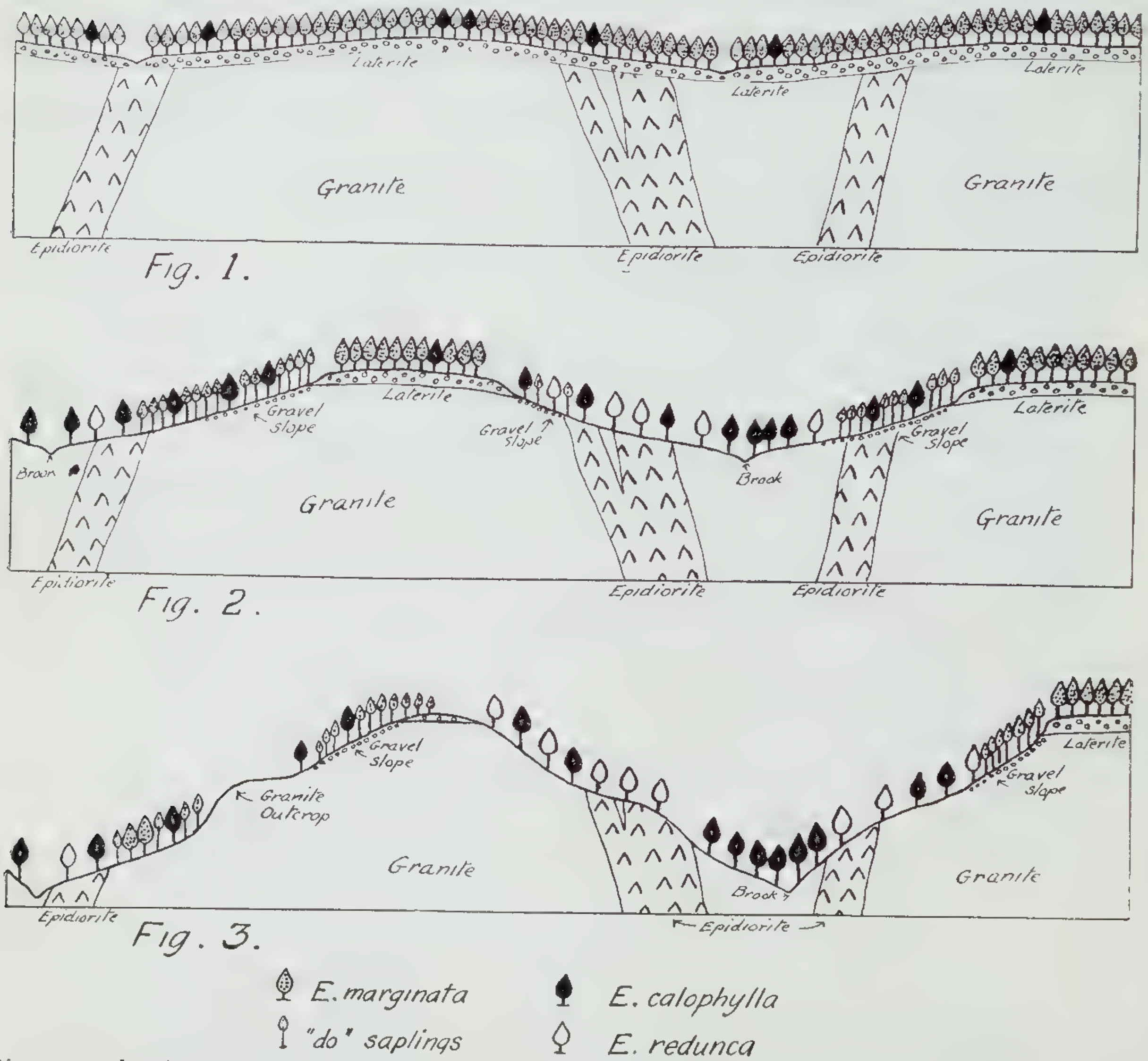
The two species *Hypocalymma robusta* and *Hakea cristata* show high constancies for the abnormal *E. marginata Association* on granite and for the area studied, are practically limited to it. Elsewhere in the Darlington Area *Hypocalymma robusta* has been observed most frequently on gravel slides. *Hakea cristata* on the other hand appears abundantly on granite and epidiorite as a colonist after severe bushfires. Both these species, therefore, would seem to support the theory that these remnants of the *E. marginata Association* are gradually giving way to the *E. calophylla-E. redunca Association.*

In concluding it is important to notice that for the *E. calophylla—E. redunca Association* all species having constancies of 3.2 and over fall within groups 1 and 2 of the classification, while, with the exception of *Melaleuca scabra,* no species with any pretence to indicator value has a constancy of more than three, even for its favourable habitat. *Melaleuca scabra* has a constancy of 5 on granite as against 3.1 for the Association as a whole.

Shrub stratum indicators of the underlying bedrock of the hill slopes are therefore practically wanting. It does not follow, however, that under more favourable conditions of slope and aspect, no such indicators could be found. From extended observation, for instance, the author is convinced that *Hakea myrtoides,* Meissn., is a fairly accurate indicator of epidioritic soils.

DISCUSSION.

The present investigation has suggested the possibility of throwing light on the origin of the valley vegetation. Assuming Jutson's Peneplanation theory (3) to be the correct key to the interpretation of the physiography



Diagrams showing successive stages in valley formation and their attendant vegetational changes.

Text Fig. 2.

of the region, it is probable that the *E. marginata Association* originally covered the whole area (Text Fig. 2, Fig. 1). As the plateau became dissected by watercourses the "Jarrah" Association would be locally destroyed by the progressive breaking away of the laterite capping. At first the gravelly slopes produced in the process could only be colonised by the con-

stituent species of the *E. marginata Association,* but as the valleys widened and deepened it would be possible for species from other Associations to immigrate and take possession of portions of the "Jarrah" region (*e.g., E. rudis,* "Flooded Gum" Association along the larger watercourses).

The composition of the *E. marginata Association* that would have developed on the gravel slopes may be assumed to have been similar to the one developed on the area studied. Here *E. calophylla* and *E. redunca* show marked increases in frequency as compared with the *E. marginata* as developed on laterite. *E. marginata* itself, though still dominant, is of course correspondingly reduced in proportional frequency (see tree analysis).

As valley formation continued, the soils of the lower slopes would be produced more from the bedrock and less from transported fragments of laterite. This fact, together with changed water relations and the different powers possessed by the three Eucalypts concerned to reproduce by seed, seems sufficient to explain the replacement of the *E. marginata Association* by the *E. calophylla-E. redunca Association.* (Text Fig. 2, Fig. 2.)

At the present time there exist extensive areas, of which the Helena River Valley is one, over which the laterite covering has been entirely removed and in which gravelly slopes are relatively insignificant. Here the soils are derived from granite and epidiorite and the two types conform for the most part with the distribution of the parent rocks. For reasons as yet unknown *E. redunca* has been able to maintain itself on epidioritic soils but has failed on granitic soils. Similarly *E. calophylla* has been successful on granitic soils and not on those derived from epidiorite. (Text Fig. 2, Fig. 3.)

The above theory therefore suggests that the *E. calophylla-E. redunca Association* has been derived directly from the *E. marginata Association* and that the Consociations of its component species are produced by segregation in response to local differences in the total environment.

In support of the above, attention is drawn to the third section of the tree analysis. The spacing for the *E. marginata Association* on gravel is 8.8 and of this community 40 per cent. of the trees are *E. calophylla* and *E. redunca.* If all the "Jarrah" were removed, an artificial *E. calophylla-E. redunca Association* would remain with a spacing of 3.5 trees per square chain. Allowing for regeneration it will be seen that this figure would tend to approach the figure for the natural mixed Association (4.5).

Again, for the mixed *E. calophylla-E. redunca Association* the number of Eucalypts per square chain is 4.5, while for the Consociations the number is about 3.0 in each case. It will be seen that the *E. redunca Consociation* could be artificially produced from the mixed Association by removing *E. calophylla* and allowing *E. redunca* to regenerate to a limited extent. The *E. calophylla Consociation* would of course be produced by the reverse process.

The space relations, therefore, of the Communities in question are in harmony with the theory and in being so lend definite support to it.

The following facts, deduced from an extended survey by compass and pacing and which was undertaken after the main field work for the present paper had been completed, indicate that the distribution of the communities is also in accord with the theory:—

1. The mixed *E. calophylla-E. redunca* community, though extensive, is rarely found below the 500′ contour line, and its upper limit usually passes into the *E. marginata Association.*
2. The bulk of the *E. calophylla* and *E. redunca Consociations* occur below the 550′ contour and they are rarely in direct contact with the *E. marginata Association,* except perhaps in very steep places. (See map.)

3. Below 500′ the agreement between the Consociations and their respective soil-types is even more striking and pronounced than it is on the area here described.

There still remains for explanation the abnormal development of *E. marginata* on what is apparently pure granitic soil. Of the three areas shown, the two smaller ones actually occur on the edge of the gravel slide, and one of them continues northward into a considerable area of typical *E. marginata Association* on gravel. This area is over 600 feet above sea-level and occupies the western side of a hill from which laterite has almost completely been removed (see Text Fig. 2, Fig. 3). The whole slope is fairly well protected from the desiccating east winds, as is demonstrated by the complete absence of *E. marginata* from the eastern slopes of the hill. The western slope must originally have had a continuous clothing of *E. marginata* saplings (Text Fig. 2, Fig. 2), but subsequent to the rejuvenation of Cohen Brook (see topographical section), rapid erosion left a large granite outcrop exposed half-way down the slope. Exceptionally favourable circumstances, therefore, have made it possible for *E. marginata* to maintain itself on this lower slope below the outcrop and have allowed the development of some relatively large specimens of "Jarrah." *E. calophylla,* however, is represented by the largest trees, and it seems probable that the community will eventually give place to the *E. calophylla* Consociation.

CONCLUSION.

With reference to indicator value the following conclusions may be stated for the area studied:—

1. The plant communities are fairly precise indicators of the soil-types.
2. The tree species, when taken separately, are poor indicators of soil-type.
3. The indicator value of shrub species for the two soil-types of the valley is negligible, and the sharp distinction between lateritic and valley shrub species is probably due more to community relations than to soil differences.

It seems probable that the "predominance of a white-barked eucalypt" used by E. de C. Clarke and F. A. Williams (2) is coincident with the *E. redunca Consociation* here described. If so, the present paper definitely affirms its observed relation with the Epidiorite dykes.

SUMMARY.

The predominant Association of the valley vegetation of part of the Darlington Area has been analysed, described, and compared with the adjacent vegetation of the plateau.

The indicator value of plant communities, trees, and shrubs was investigated and a tentative theory has been advanced to explain the origin of the *E. calophylla-E. redunca Association* and its Consociations.

In closing I desire to express my sincere thanks to Mrs. E. R. L. Johnson for constant advice and for constructive criticism during the preparation of the present paper. To Professor E. de C. Clarke and the Department of Geology I am indebted for the use of surveying instruments and of their Draughting Room. I also desire to thank all fellow students and friends who assisted with the field work.

The Government Botanist, Mr. C. A. Gardner, has carefully checked my identifications of the species mentioned in the paper, and all specific names refer to his Census of Western Australian Plants (6).

TABLE 3.

TREE ANALYSIS.

Total No. of Trees—1,825. Total No. of Eucalypts—1,687. Area—440 sq. chns.

Part 1. Communities.		Eucalyptus calophylla, R.Br.	E. redunca, Schau. var. elata.	Eucalyptus marginata, Sm.	Nuytsia floribunda (Labill).	Casuarina Fraseriana, Miq.	Totals.
E. calophylla-E. redunca Association.							
a. Excluding Consociations	No. ...	303	197	1	24	—	525
	% Eucalypts	*61*	*39*	—	—	—	
b. E. calophylla Consociation	No. ...	192	5	—	44	—	241
	% Eucalypts	*97*	*3*	—	—	—	
c. E. redunca Consociation	No. ...	2	295	—	—	—	297
	% Eucalypts	*1*	*99*	—	—	—	
d. Entire Association	**No.** ...	**497**	**497**	**1**	**68**	—	**1063**
	Per cent.	*47*	*47*	—	*6*	—	
	% Eucalypts	*50*	*50*	—	—	—	
E. marginata Association							
e. On Laterite excluding Casuarina Society	No. ...	18	9	101	—	14	142
	% Eucalypts	*14*	*7*	*79*	—	—	
f. On Gravel slide ...	No. ...	85	54	206	14	—	359
	% Eucalypts	*25*	*16*	*59*	—	—	
g. On Granite ...	No. ...	73	11	129	7	—	220
	% Eucalypts	*34*	*5*	*61*	—	—	
h. Casuarina Society...	No. ...	1	1	4	—	35	41
j. Entire Association ...	**No.** ...	**177**	**75**	**440**	**21**	**49**	**762**
	% Eucalypts	*26*	*11*	*63*	—	—	
	Totals ...	**674**	**572**	**441**	**89**	**49**	**1825**

Part 2. Soil Types (Indicator Value).		Eucalyptus calophylla, R.Br.	E. redunca, Schau. var. elata.	Eucalyptus marginata, Sm.	Nuytsia floribunda (Labill).	Casuarina Fraseriana, Miq.	Totals.
Granite	No. ...	277	65	122	52	—	516
	% Eucalypts	*60*	*14*	*26*	—	—	
Epidiorite	No. ...	74	192	3		—	269
	% Eucalypts	*28*	*71*	*1*	—	—	
Gravel slide ...	No. ...	304	305	211	37	—	857
	% Eucalypts	*37*	*37*	*26*	—	—	
Gravel slide— 1. over granite ...	% Eucalypts	*70*	*30*	—	—	—	
2. over epidiorite...	% Eucalypts	*16*	*84*	—	—	—	
Laterite	No. ...	19	10	105	—	49	183
	% Eucalpyts	*14*	*7*	*79*	—	—	
	Totals ...	674	572	441	89	49	1825

TABLE 3—*continued.*

TREE ANALYSIS—*continued.*

Part 3. Space Relations Community	No. of Eucalypts.		Area in Sq. Chains.		No. per Sq. Chain.
E. calophylla — E. redunca Association:					
a. Excluding Consociations	501		112		4·5
b. E. calophylla Consociation ...	197		71		2·8
c. E. redunca Consociation	297		94		3·2
d. Entire Association		995		277	3·6
E. marginata Association:					
e. On Laterite excluding Casuarina Society	128		16		8·0
f. On Gravel slide	345		41		8·4
g. On Granite	213		15		14·2
h. Casuarina Society	6		3		2·0
j. Entire Association		692		75	9·2
Seral Areas		...		35	
Not Mapped		...		53	
Totals		1,687		440	

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5. Smith, W. G., "Raunkiaer's Life Forms and Statistical Methods." Journal of Ecology, Vol. I., p. 16 (1913).

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TABLE 4.

SHRUB ANALYSIS.

"A" E. calophylla – E. redunca Association
"B" E. marginata Association on granite.
"C" Laterite.
"D" Gravel slide.
"E" Granite.
"F" Epidiorite.

Species.	"A."		"B."		"C."		"D."		"E."		"F."	
No. of Samples ...	157	10	20	10	20	10	56	10	66	10	35	10
Acacia pulchella, R. Br.	137	8·8	17	8·5	...	...	47	8·5	63	9·5	27	8
Acacia decipiens, R. Br.	5	0·3	...	...	...	...	1	–	...	...	4	1
Adenanthos barbigera, Lindl. ...	...	...	...	...	4	2	...	...	...	...	...	...
Andersonia sprengelioides, R. Br. ...	56	3·5	...	...	...	...	20	3·5	30	4·5	6	2
Astroloma pallidum, R. Br. ...	56	3·5	3	1·5	2	1	18	3	21	3	17	5
Baeckea camphorosmae, Endl. ...	77	4·9	3	1·5	1	0·5	30	5·5	27	4	20	5·5
Bossiaea biloba, Benth.	58	3·7	...	...	...	...	16	3	28	4	14	4
Bossiaea, ornata (Lindl.)	...	...	5	2·5	19	9·5	...	...	...	...	...	...
Casuarina humilis, Otto et Dietr. ...	26	1·6	...	...	...	...	13	2·5	8	1	5	1·5
Chorizema Dicksonii, Grah. ...	24	1·5	2	1	...	...	5	1	16	2·5	3	1
Conostylis setigera, R. Br., var. discolor	...	...	...	...	11	5·5	...	...	...	...	...	...
Dampiera linearis, R. Br. ...	24	1·5	14	7	13	6·5	13	2·5	11	1·5	...	...
Dampiera alata, Lindl.	17	1·0	10	5	...	...	10	2	4	0·5	3	1
Daviesia brevifolia, Lindl. ...	10	0·6	...	...	...	...	1	–	4	0·5	5	1·5
Daviesia horrida, Meissn. ...	9	0·5	...	...	...	...	3	0·5	3	0·5	3	1
Daviesia pectinata, Lindl. ...	16	1·0	4	2	15	7·5	11	2	3	0·5	2	0·5
Daviesia polyphylla, Benth. ...	27	1·7	...	...	...	...	12	2	11	1·5	4	1
Dillwynia cinerascens, R. Br. ...	15	1·0	...	...	...	...	7	1·5	6	1	2	0·5
Dryandra armata, R. Br. ...	19	1·2	...	...	...	...	...	...	19	3	...	...
Dryandra nivea, R. Br.	116	7·4	17	8·5	15	7·5	46	8	44	6·5	26	7·5
Eriostemon spicatum, A. Rich. ...	31	2·0	8	4	...	...	10	2	17	2·5	4	1
Gastrolobium epacridioides, Meissn.	26	1·6	...	...	...	...	13	2·5	13	2	...	...
Gompholobium marginatum, R. Br.	19	1·2	1	0·5	5	2·5	1	(?)	9	1·5	9	2·5
Gompholobium polymorphum, R. Br.	12	0·8	1	0·5	...	...	...	...	12	2	...	...
Grevillea bipinnatifida, R. Br. ...	10	0·6	...	...	...	...	1	–	6	1	3	1
Grevillea pilulifera (Lindl.) ...	81	5·1	6	3	...	...	23	4	35	5·5	23	6·5
Grevillea synapheae, R. Br. ...	...	...	...	...	13	6·5	...	...	...	...	...	...
Hakea bipinnatifida, R. Br. ...	72	4·5	5	2·5	11	5·5	30	5·5	19	3	23	6·5
Hakea cristata, R. Br.	2	0·1	11	5·5	...	...	...	...	...	...	2	0·5
Hakea erinacea, Meissn.	17	1 0	...	...	...	...	4	0·5	4	0·5	9	2·5
Hakea incrassata, R. Br. ...	25	1·5	...	...	...	...	2	0·5	20	3	3	1
Hakea stenocarpa, R. Br. ...	14	0·9	2	1	...	...	1	–	13	2	...	...
Hakea trifurcata (Sm.)	34	2·2	...	...	...	...	17	3	8	1	9	2·5
Hakea undulata, R. Br. ...	69	4·4	9	4·5	...	...	24	4·5	33	5	12	3·5
Hibbertia hypericoides (D.C.) ...	150	9·5	20	10	20	10	54	9·5	64	9·5	32	9·5
Hibbertia montana, Steud. ...	121	7·7	8	4	16	8	43	7·5	49	7·5	29	8·5
Hibbertia pachyrrhiza, Steud. ...	...	...	...	...	7	3·5	...	...	...	...	...	...
Hibbertia polystachya, Benth ...	31	2·0	...	...	...	...	7	1·5	13	2	11	3
Hovea chorizemifolia (Sweet) ...	1	0·1	2	1	14	7	1	–	...	...	...	...
Hovea trisperma, Benth. var. crispa	71	4·5	16	8	7	3·5	23	4	35	5·5	13	3·5
Hypocalymma angustifolia, Endl.	78	5·0	3	1·5	...	...	23	4	32	5	23	6·5
Hypocalymma robusta, Endl. ...	...	...	19	9·5	...	...	...	...	...	...	...	...
Isopogon asper, R. Br.	32	2·1	1	0·5	...	...	16	3	6	1	11	3
Isopogon sphaerocephalus, Lindl.	...	...	...	...	8	4	...	...	...	...	...	...
Kennedya coccinea, Vent. ...	...	...	4	2	5	2·5	...	...	...	...	...	...
Leucopogon sprengelioides, Sond.	97	6·2	2	1	...	...	30	5·5	46	7	21	6
Leschenaultia biloba, Lindl. ...	1	0·1	1	0·5	10	5	1	–	...	...	...	...
Melaleuca scabra, R. Br. ...	49	3·1	...	...	...	...	10	2	34	5	5	1·5
Olearia paucidentata, (Steetz.) ...	26	1·6	4	2	4	2	9	1·5	11	1·5	6	2
Oxylobium cuneatum, Benth. ...	15	1·0	8	4	...	...	13	2·5	2	0·5	...	...
Petrophila seminuda, Lindl. ...	11	0·7	...	...	...	...	3	0·5	2	0·5	6	2
Petrophila striata, R. Br. ...	21	1·8	...	...	3	1·5	9	1·5	12	2	...	...
Phyllanthus calycinus, Labill. ...	12	0·8	2	1	...	...	2	0·5	2	0·5	8	2·5
Pimelea rosea, R. Br.	24	1·5	14	7	...	...	...	...	14	2	10	3
Pultenaea ericifolia, Benth. ...	12	0·8	...	...	...	...	3	0·5	9	1·5	...	...
Sphaerolobium medium, R. Br. ...	50	3·2	16	8	7	3·5	8	1·5	31	4·5	11	3
Styphelia tenuiflora, Lindl. ...	...	...	...	...	5	2·5	...	...	...	...	...	...
Synaphaea acutiloba, Meissn. ...	31	2·0	...	...	...	...	10	2	19	3	2	0·5
Synaphaea petiolaris, R. Br. ...	27	1·7	6	3	14	7	12	2	8	1	7	2
Synaphaea pinnata, Lindl. ...	18	1·1	...	...	...	...	5	1	2	0·5	11	3
Tetratheca hirsuta, Lindl. ...	36	2·3	3	1·5	(6	3)*	2	0·5	21	3	13	3·5
Thomasia glutinosa, Lindl. ...	22	1·4	2	1	...	...	7	1·5	9	1·5	6	2
Trymalium ledifolium, Fenzl. ...	10	0·6	...	...	...	...	...	...	2	0·5	8	2·5

* Possibly a distinct variety of T. hirsuta.

INDEX TO QUADRAT CHARTS (PLATE VI.).

E. marginata Association (Fig. 1).

Total number of specimens 261.

B.	Bossiaea ornata (Lindl.) ...	103	I.	Isopogon sphaerocephalus, Lindl.	4
L.	Leschenaultia biloba, Lindl....	19	O.	Olearia paucidentata (Steetz)...	4
G.	Grevillea synapheae, R. Br. ...	13	Hp.	Hibbertia pachyrrhiza, Steud.	2
Al.	Astroloma longiflorum ...	13	Td.	Thysanotus dichotomus (Labill)	2
H.	Hibbertia hypericoides (D.C.)	12	A.	Adenanthos barbigera, Lindl.	2
Ho.	Hovea chorizemifolia (Sweet)...	11	Lo.	Lomandra Endlicheri (F. v. M.)	2
D.	Dryandra nivea, R. Br. ...	11	S.	Synaphaea petiolaris, R. Br. ...	1
Sh.	Stylidium hispidum, Lindl. * ...	10	Lp.	Leucopogon propinquus, R. Br.	1
Da.	Dampiera linearis, R. Br. ...	10	La.	Labichea punctata, Benth. ...	1
C.	Conostylis setigera, R. Br. v. discolor	8	P.	Petrophila striata, R. Br. ...	1
T.	Tetratheca hirsuta, Lindl. ...	8	Sm.	Sphaerolobium medium, R. Br.	1
St.	Styphelia tenuiflora, Lindl. ...	8	Gp.	Gompholobium Preissii, Meissn.	1
Hb.	Hakea bipinnatifida, R. Br. ...	7	X.	Xanthosia peltigera (Hook.) ...	1
Dp.	Daviesia pectinata, Lindl. ...	5			

E. calophylla—E. redunca Association (subseral area after repeated bush-fires (Fig. 2).

Total number of specimens 67.

A.	Acacia pulchella, R. Br. ...	31	Ht.	Hakea trifurcata (Sm.) ...	3
Hy.	Hypocalymma angustifolium, Endl.	12	Gs.	Gastrolobium spathulatum, Benth.	2
D.	Dryandra nivea, R. Br. ...	9	Hc.	Hakea cristata, R. Br. ...	2
H.	Hibbertia hypericoides (D.C.)	3	L.	Leucopogon sprengelioides, Sond.	1
S.	Sedge (unidentified)	4			

E. calophylla—E. redunca Association (Fig. 3).

Total number of specimens 326.

A.	Acacia pulchella, R. Br. ...	73	Gp.	Grevillea pilulifera (Lindl.) ...	5
H.	Hibbertia hypericoides (D.C.)	62	O.	Olearia paucidentata (Steetz)	5
S.	Sphaerolobium medium, R. Br.	25	Ap.	Astroloma pallidum, R. Br. ...	4
Ho.	Hovea trisperma, Benth. v. crispa	22	Bc.	Baeckea camphorosmae, Endl.	4
Hm.	Hibbertia montana, Steud. ...	21	C.	Casuarina humilis, Otto et Dietr.	4
As.	Andersonia sprengelioides, R. Br.	18	P.	Petrophila striata, R. Br. ...	4
Hb.	Hakea bipinnatifida, R. Br. ...	17	I.	Isopogon asper, R. Br. ...	3
D.	Dryandra nivea, R. Br. ...	11	Dp.	Daviesia pectinata, Lindl. ...	3
B.	Bossiaea biloba, Benth. ...	8	Ox.	Oxylobium cuneatum, Benth.	3
Cd.	Chorizema Dicksonii, Grah. ...	6	Hu.	Hakea undulata, R. Br. ...	2
G.	Gompholobium marginatum, R. Br.	6	M.	Mesomelaena tetragona (R. Br.) *	2
L.	Leucopogon sprengelioides, Sond.	6	Sp.	Synaphaea petiolaris, R. Br. ...	2
Hy.	Hypocalymma angustifolium, Endl.	6	Hs.	Hakea stenocarpa, R. Br. ...	2
			X.	Xanthorrhoea Preissii, Endl....	1
			Da.	Dampiera linearis, R. Br. ...	1

* Identification doubtful.

N.B.—The areas bounded by dotted lines indicate the extent of lateral spread of the larger undershrubs. Similarly the radiating lines around X. and M. in Fig. 3 show the extent of the radiating leaves of a young "Blackboy" and of a sedge.

PLATE VI.
QUADRAT CHARTS.

Each quadrat measures 5 yards by 3 yards (4.57 x 2.74 metres).

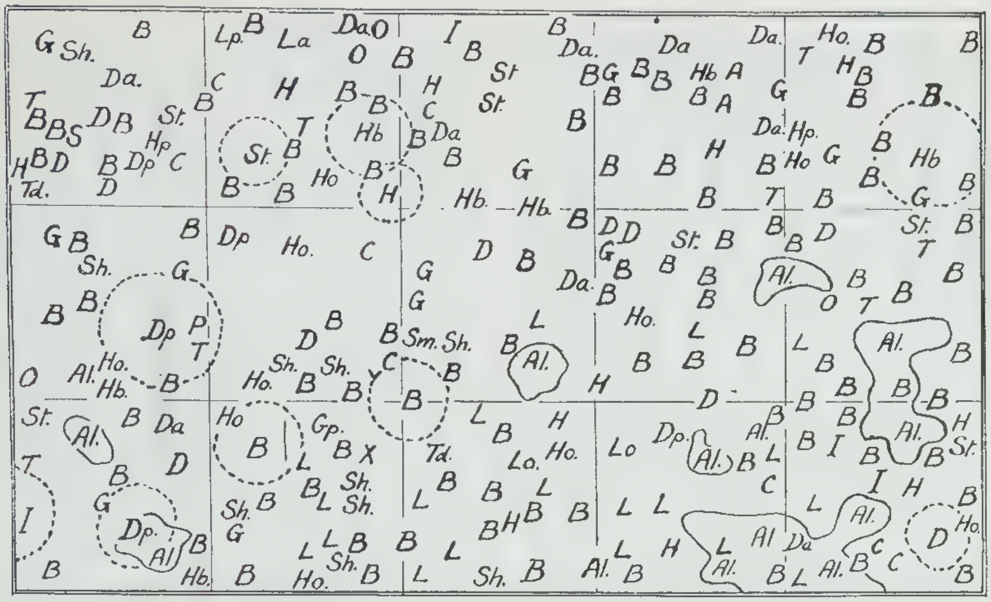

Fig. 1.

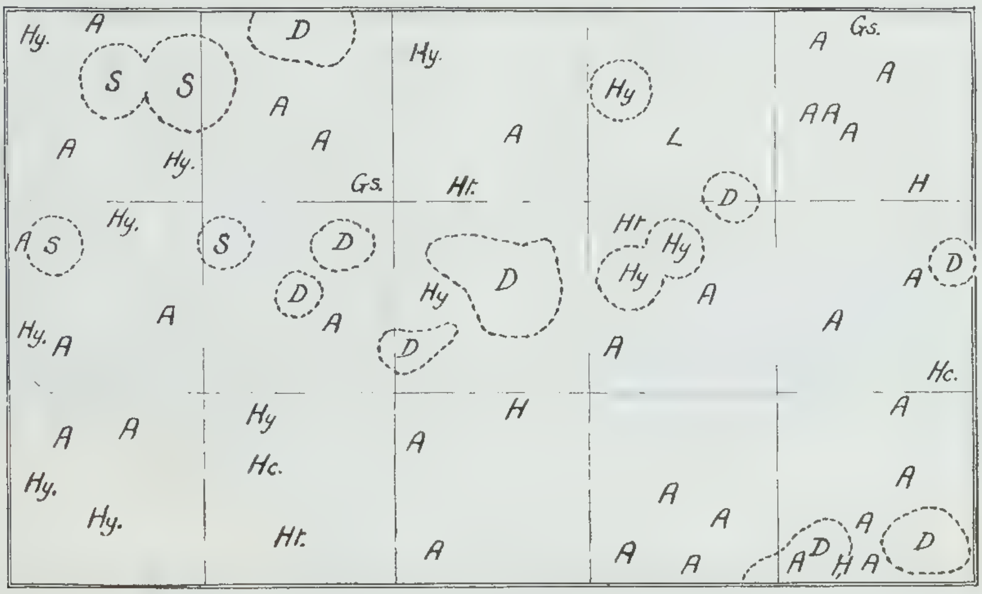

Fig. 2.

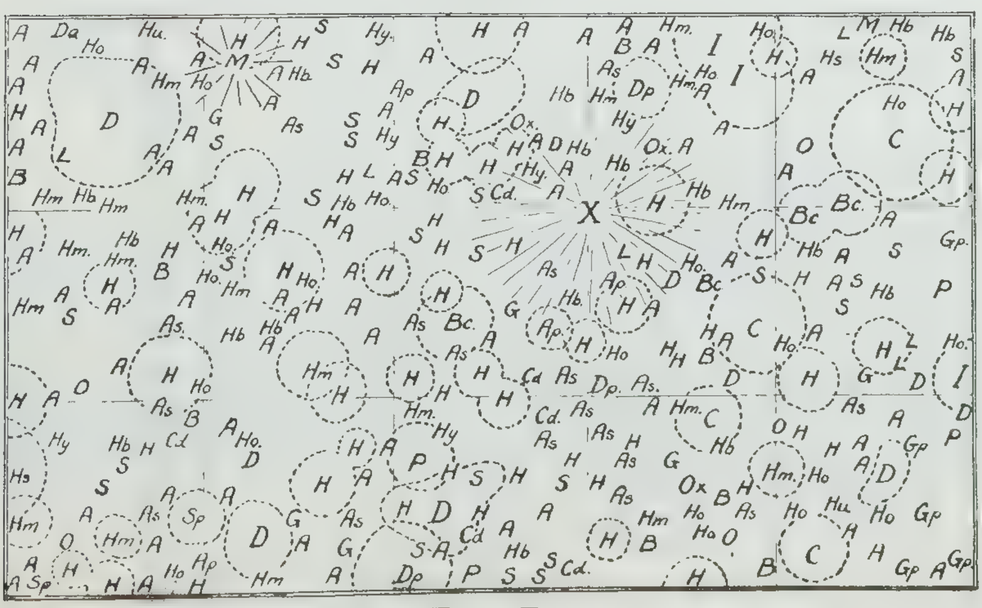

Fig. 3

PLATE VII.

E. redunca Consociation on gravel slide.
Fig. 1.

E. marginata Association on laterite.
N.B.—Scanty shrub-stratum and leaf litter.
Fig. 2.

E. calophylla-E. redunca Association on Granite.
Fig. 3.

PLATE VIII.

— FIG. 1. —

SHOWING TREES, GEOLOGY, SOIL-TYPES, AND PHYSIOGRAPHY.

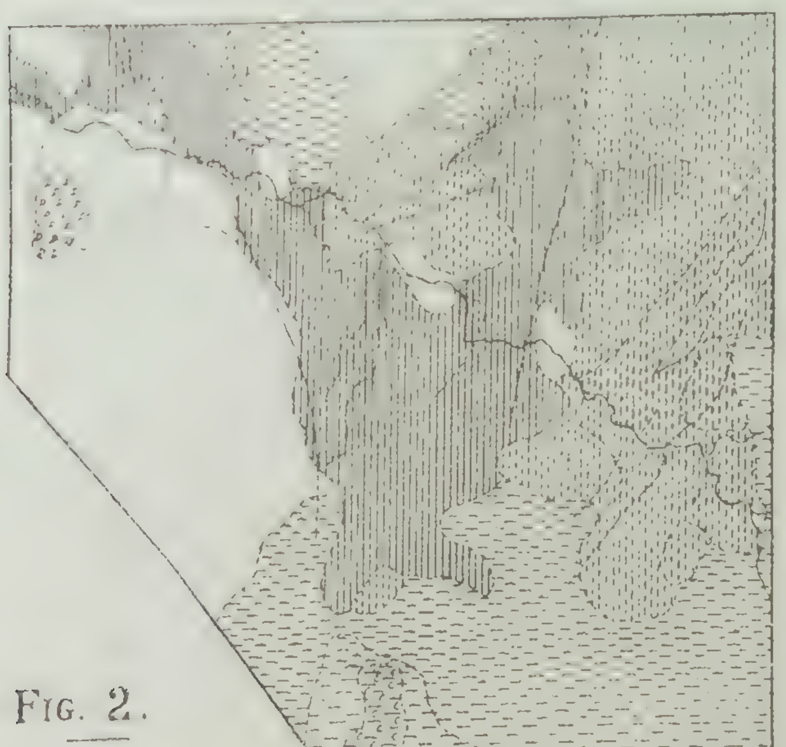

FIG. 2.

KEY TO PLANT COMMUNITIES
Fig. 2.

- E. calophylla - E. redunca (mixed) Association
- E. redunca Consociation
- E. calophylla Consociation
- E. marginata Association
- Casuarina Fraseriana Society
- Dryandra floribunda Society

LOCALITY PLAN

VEGETATION MAP OF AN AREA NEAR DARLINGTON, WESTERN AUSTRALIA.

By Authority: FRED. WM. SIMPSON, Government Printer, Perth.

JOURNAL OF THE ROYAL SOCIETY OF WESTERN AUSTRALIA,
VOL. XVIII., 1931-32.

11.—MINERALOGY OF THE FINE SAND FRACTIONS OF SOME AUSTRALIAN SOILS.

By DOROTHY CARROLL, B.A., B.Sc. (Hons.).

Read 14*th June*, 1932. *Published* 3rd *August*, 1932.

TABLE OF CONTENTS.

I.—INTRODUCTION.

This paper describes a series of investigations carried out on the fine sand fractions of soils with the object of correlating their mineral constituents with soil types. The work was done in the Department of Geology, University of Western Australia, during the latter part of 1930 and throughout 1931.

DISTRIBUTION OF SOIL ZONES IN AUSTRALIA.

The soil zones of Australia have been tentatively mapped by Prescott (17, p. 124),[1] who divides Australia into the following zones:—

1. *Desert* (sandy).—Formed under arid conditions; sand ridges, etc.
2. *Desert Steppe.*—Formed under arid conditions and may be sandy or stony.
3. *Mallee.*—Alkaline soils formed under low rainfall ranging from 10-15 inches; the rain falls in the winter. The soils vary from sands to clays and show an accumulation of calcium carbonate in the subsoil at a depth of from 8 to 20 inches. pH is about 8. (24, p. 83.)
4. *Brown Earths.*—Less alkaline than the Mallee soils, and developed under rainfall of 15-25 inches. 6.0 to 7.5 appears to be the pH range. Bases and sesquioxides are leached and distributed throughout the profile. (24, p. 83.)
5. *Chestnut Earths.*—Formed under fairly arid conditions, alkaline bases are leached and alkaline earth bases accumulate; little organic matter formed.
6. *Black Earths.*—Very similar to the Chestnut Earths but formed under slightly less arid conditions with the accumulation of organic matter.
7. *Podsolised Soils.*—Formed under fairly high rainfall conditions which cause leaching of the bases and sesquioxides to a lower horizon where they may accumulate as a pan. Reaction is on the acid side.

In mapping the soil zones of Australia, Prescott has followed the Russian agriculturalists in basing his map upon climatic considerations (9, p. 8). In each soil zone the climatic agencies have worked together to produce soils having more or less closely related characteristics. Within each soil zone there are recognised normal soils which have developed from known igneous or sedimentary rocks, such as granite, sandstone or shale. In these local types the minerals present in the fine sands will reflect the mineralogical character of the parent rock, modified by the weathering to which it has been subjected. Transported soils of any kind will contain minerals which may differ widely from those of the rocks on which they happen to be resting (16, p. 464). These minerals may be conspicuously rounded, and an examination of the grains microscopically may indicate the amount of wear to which they have been subjected (4, p. 668). The grains of loess soils, however, do not show this rounding, because they have been carried in suspension great distances by the wind.

[1] Numbers refer to the bibliography.

From a consideration of the minerals composing acid and basic igneous rocks, it will be seen that the proportion of heavy to light minerals in the fine sand fraction will show whether the soil has been derived from granitic or basic rocks. Soils derived from basic igneous rocks have a larger amount of heavy minerals in the fine sand than those derived from acid igneous rocks or from sedimentary rocks.

Soils resulting from the weathering of metamorphosed sediments may resemble in mineralogical character soils from acid or basic igneous rocks, depending on the original nature of the sediments. Characteristic metamorphic minerals such as kyanite, sillimanite, and staurolite may be present.

There are, in addition, soils which are thought to be abnormal in that they do not show the characteristic features of the zone in which they occur. Such, for example, are the lateritic soils now forming from ancient laterites which are thought to have been themselves once soils developing under warm, moist climatic conditions. These lateritic soils retain some of the characters of true laterites which could not develop with the present climate in the southern part of the continent (15, p. 534). The lateritic soils have an acid reaction which is believed to have persisted from the earlier period of formation of the original laterites (24, p. 82). In other words, the soils are endodynamomorphic or immature, the present climatic conditions not having been continued for a sufficient length of time to make much impression on the soil. Lateritic soils cover wide areas in Western Australia, and, as they are infertile, present a very real economic problem. Careful investigation is needed before the relationship between the soil and the original underlying rock can be worked out mineralogically.

Another type of immature soil is the Rendzina, or lime-humus soil, which is developed on the chalk at Gingin, W.A. This soil gives an alkaline reaction in a soil zone where the reaction should be acid (24, p. 84).

II.—METHOD OF INVESTIGATION.

A.—SOURCE OF SOIL SAMPLES.

As far as possible, the soils examined were from areas where soil surveys have been made and represent profile samples (18, p. 9; 19, p. 32; 9, p. 9-12). A profile sample is one which has been obtained from a definite horizon in a vertical section from the surface of the soil to the underlying rock.

The fine sand fraction of a soil contains the particles ranging from 0.2-0.02 mm. in the International System of Mechanical Analysis (18, p. 10). It has been found that this is the best fraction for the examination of the mineral constituents (13, p. 260).

The fine sands used for this investigation were obtained from the following sources:—

(1) Samples collected by Dr. L. J. H. Teakle, Department of Agriculture, Perth, W.A. Mechanical analyses of these were made by Mr. B. L. Southern, A.A.C.I., Government Chemical Laboratory, W.A.

Esperance, W.A.
Lake Brown, W.A.
Lake Kathleen, W.A.
Lake King, W.A.

(2) Samples collected by Dr. Teakle, the mechanical analyses being carried out by the author, using the Kuhn cylinder method.
Isseka, W.A.
Peak Charles, W.A.

(3) Fine sands of soils mechanically analysed in the Government Chemical Laboratory, W.A.
Dajoing, W.A.
Nornalup, W.A.

(4) Fine sands of soils mechanically analysed at the Waite Institute, Adelaide, and kindly sent over by Professor J. A. Prescott.
Auburn, S.A.
Clifton, Q.
Coomealla, N.S.W.
Forth, Tas.
Glen Osmond, S.A.
Kuitpo, S.A.
Lyonville, Vic.
Merriwa, N.S.W.
Meteor Downs, Q.
Mirrool, N.S.W.
Mount Barker, S.A.
Mt. Gambier, S.A.
Renmark, S.A.
Roto, N.S.W.
Yurgo, S.A.

(5) Samples collected by Mr. R. T. Prider, B.Sc., mechanically analysed by the author.
Jimperding, W.A.
Narrogin, W.A.

(6) Samples collected and mechanically analysed by the author.
Augusta, W.A.
Alexandra Bridge, W.A.
Bunbury, W.A.
Donnybrook, W.A.
Kulikup, W.A.
Katanning, W.A.

Soil Sample Localities.—The localities from which soil samples were obtained were placed on Prescott's map in order to show the soil zones in which they occur. In Part IV. of this paper the latitude and longitude of the sample localities have been added, so that by referring to Prescott's map (17, p. 124) the soil zones in which they occur can be readily ascertained.

In the earlier stages of this work a map was constructed showing isohyets, soil zones, and geology. Since, however, the mineral content of soils is largely dependent on the mineralogical character of rocks, and not on their ages, it soon became apparent that the information supplied by a general geological map was of very little significance in pedological problems. For a geological map to be of any value in soil work the details supplied should be of a petrological rather than of an historical character.

B.—IDENTIFICATION OF MINERALS AND EXPRESSION OF RESULTS.

The usual procedure of preparing the samples before the microscopic identification of minerals consisted of cleaning with dilute acid (oxalic acid gave the best results), washing, drying, and separating into light and heavy fractions by means of bromoform (S.G. about 2.9). Where there was a large amount of heavy fraction, an electro-magnetic separation followed, but was not entirely satisfactory, as it was found that any one mineral varied in magnetic properties from sample to sample and separation by the electro-magnet was discontinued. It was found that some samples could be separated into light and heavy fractions sufficiently well by panning. The basaltic soils from the Eastern States received this treatment.

For the microscopic identification of the minerals part of each fraction was mounted in clove oil of known refractive index (1.53 was found satisfactory). After a rapid glance over the mount, any minerals not easily identified were removed, and the refractive index determined by a set of refractive index liquids (14, p. 15). A useful test for refractive index was made with the Leitz petrological microscope by introducing a shadow above the objective with the brass edge of the mica or gypsum plate. If the mineral tested has a higher refractive index than the liquid surrounding it, the edge nearest the shadow becomes dark, and if lower than that of the liquid, the nearest edge becomes white or very light, and the further edge dark. The test is quickly made and will show very small differences in refractive index. If the surrounding liquid and the mineral are of very nearly the same refractive index, a blue colour appears on one side of the mineral grain and a yellow colour on the opposite, when the shadow is introduced. This method has been found very useful where a large number of grains have to be dealt with fairly rapidly, as in traversing across a light fraction of quartz and felspar.[2] The minerals were identified by the usual optical tests, and comparisons made with a standard set of detrital minerals.

Method of expressing Results.

In order to obtain some idea of the relative abundance of the minerals present, the method set out in Milner's Sedimentary Petrography, p. 386, has been followed, but it would have been better to have counted the number of grains of each mineral present in each mount. The figures given in Table I. are based on Milner's method and give the relative proportions of mineral species present, but are not very definite, as they are a personal expression of the relative abundance.

The following scheme has been adopted from Milner:—

Term—	
Flood	9
Very Abundant	8
Abundant	7
Very Common	6
Common	5
Scarce	4
Very Scarce	3
Rare	2
Very Rare	1
Present	P

[2] This method cannot be employed with every type of petrological microscope.

C. Relation of Light to Heavy Fractions.

It has not been found possible to determine the relative amounts of light and heavy fractions. It was hoped that the percentage by weight of the heavy mineral fraction could be obtained by weighing the sample before separation with bromoform and weighing the light fraction after separation, washing and drying. But the separation, however carefully carried out on the small samples many of which only weighed about 2 grams, always left some of the heavy minerals attached by surface tension and interlocking of grains to the light fraction, and some of the light fraction always remained sticking to the rubber tubing used at the ends of the separating funnels. The weight, obtained by difference between the light fraction and the total sample, was unreliable and gave a false idea of the heavy mineral contents. With larger particles the separation would probably have been less liable to error.

For this reason it would be misleading to make any definite statements about the relative proportions of heavy and light fractions, but in all the samples examined, except those from basaltic soils, the heavy fraction obtained from about 2 grams of find sand has been very small in quantity, often being only sufficient to spread thinly under a circular cover-glass.

The usefulness of accurate determination of the proportion of light to heavy fractions is connected with fertility problems. A soil consisting mainly of quartz grains is of low fertility, whereas basaltic soils which are of proved fertility, have a high proportion of heavy to light fractions. But the quality as well as the quantity has to be taken into consideration.

The amount of heavy fraction is important in assisting in the distinction between granitic soils and basic igneous rock soils. There are many gradations between the two types, but where there are underlying granitic rocks, from which the soil above them was formed (sedentary soils), only a very minute amount of heavy fraction is obtained. When further investigations have been made this may have an important bearing on the geological mapping of obscured areas. Rocks containing any special mineral could readily be traced by the mineral content of the overlying soil. (21 p. 499.)

III. MINERALOGY OF THE FINE SANDS.

A. Description of the Identified Minerals.

In the appended tables the heavy minerals have been placed in six groups, the first five of which are based on the chemical composition of the minerals. The sixth group contains miscellaneous minerals placed together for convenience. The light minerals are grouped separately. The same grouping has been followed in the description of the minerals. The following characteristics of the minerals identified are those which were observed in the samples examined.

Titanium minerals.

Ilmenite: Black, opaque; often covered with leucoxene, but when this is absent the lustre is metallic. Rounded to sub-angular; crystal faces scarce.

Leucoxene: White to pale yellow, rounded, opaque grains.

Rutile:

(a) Red-brown, rounded, stumpy prisms; geniculate and arrow-head twins are found, but are not common.

(b) Yellow, slender, acicular prisms often with sharp edges and capped by pyramids.

The yellow variety may be developed in situ, the red being derived from the parent rock.

? Sphene: Yellow grains often with small crystal faces, non-rounded.

Anatase: Colourless to yellow; in flat, rectangular crystals with bevelled edges; sometimes slightly rounded. Also in small, acicular prisms growing together. Anatase is nearly always authigenic. (16, p. 445; 3, p. 24; 6, p. 334.)

Iron minerals.

Hematite: Small, red-brown flakes with high refractive index.

Limonite: Rounded earthy grains; coats many mineral grains.

Magnetite: Small, rectangular to rounded grains; black, opaque with metallic lustre.

? Pyrite: Brass-yellow, opaque masses, often with grooved surfaces.

Epidote group.

Epidote: Yellow-green cleavage and broken fragments, some slightly rounded; moderately pleochroic; refractive index high.

Ferromagnesians.

Hornblende:

(a) Dirty, green-brown, pleochroic cleavage fragments.

(b) Blue-green, small, irregular, very pleochroic fragments.

(c) Practically colourless grains of fairly large size.

Augite: Yellow-green to pale brown-green grains, often somewhat rounded. Character is fairly constant through a large number of samples.

Mica group.

Biotite: Pale brown, basal fragments; edges often corroded.

Muscovite: Colourless, basal fragments yielding excellent interference figures; edges uncorroded in contrast to biotite.

Miscellaneous group.

Garnet: Colourless to pale pink and brown; most grains are broken fragments and non-rounded; surface of some grains mammilated.

Tourmaline:

(a) Brown-green, sharp-edged, small prisms.

(b) Rounded, fairly large basal sections; blue, brown, green or gray.

(c) Stout prisms, pleochroic pink to green.

(d) Ragged, irregular, blue flakes; weakly pleochroic.

Pleonaste: Bright green to pale yellowish-green (Lake Brown soil), isotropic grains, slightly rounded; not a common mineral of soils.

Andalusite:

(a) A single prismatic grain with dark inclusions was noted in the Lake Kathleen soil.

(b) Large, colourless, broken fragments showing good figures; very slightly pleochroic.

? Topaz: Colourless, broken grains.

Kyanite: Colourless, cross-fractured grains.

Sillimanite: Colourless, elongated grains with parallel extinction and low interference colours; some grains in fibrous aggregates.

Zircon:

(a) Stumpy, rounded prisms capped by pyramids; colourless to yellowish.

(b) Zoned, prismatic grains; inclusions common; often brown to yellow.

(c) Twinned crystals; geniculate twins of colourless stumpy individuals, not at all common.

(d) Fine, acicular, colourless, usually clear cystals sometimes containing a few dark inclusions; may have been released from biotite. (16, p. 440.)

? Monazite: Yellow-green, rounded grains slightly pleochroic and with high refractive index.

Staurolite: Broken fragments, yellow-brown and pleochroic; one perfect cruciform twin, pale yellow in colour and very pleochroic was found in the soil from Lake Brown, W.A.

? Chlorite: Pale green, irregular masses with low polarisation colours. Obviously a decomposition product.

Light Fraction.

Quartz: The most common mineral of soils. Angular to sub-angular grains, rounded grains rare in most samples. Usually colourless but pale yellow in some samples. Inclusions not very common, but some soils have quartz grains with many rutile needles. Small colourless apatite rods have sometimes been seen as inclusions, but these are rare.

Orthoclase: Occurs in fairly large, rounded grains often clouded with alteration products.

Plagioclase: Small, colourless, rectangular cleavage fragments; twin lamellae when present are very fine. Untwinned plagioclase distinguished from orthoclase by refractive index.

Microcline: Small fragments exhibiting cross-hatching under crossed nicols.

Microperthite: A few cleavage fragments with a fine moiré appearance. Present in a number of soils but always in small amount.

Kaolinised material: Small, rounded grains, yellowish-brown to colourless; somewhat opaque.

Sponge Spicules.

Opaline silica, isotropic. Usually occur in broken pitted fragments. Soils near the coast contain larger and more complete spicules than those farther inland. Spicules are often present in the soil down to a considerable depth (over three feet is common), but in a sample from Lake Brown, W.A., small fragments of spicules were found down to a depth of 11 feet. A mount of the light fraction from Lake King, W.A., was sent to Mr. F. Chapman, of Melbourne, who identified the spicules as the longoxea or principal skeletal of a marine sponge like Ecionema. The smaller rod-shaped bodies probably belong to the same or a related species.

Spicules were found in practically all the soils examined and appear to be commonly present in soils in many parts of the world, though references to their occurrence are not numerous. Javanese soils always contain spicules and other siliceous remains. J. B. Scrivenor reports spicules in a soil in Malaya (Geol. Mag. Sept. 1930, p. 385). The soils of U.S.A. and Holland

also contain spicules and other small organic remains, which are dismissed as unimportant (J. K. Plummer J. Agric. Res. V. 1915-1916, p. 569-581; 1, p. 37 & 67).

The suggestion is made here that the spicules in Australian soils have been carried inland by wind, and deposited. Chapman mentions that they occurred in the red rain which fell in Victoria in 1927, and they have been observed, together with other minute remains, in similar circumstances in America. It is curious to find that they occur to such depths (see Table I.), but could perhaps have been washed down by rain. In other countries a recent elevation from below sea-level has been postulated to account for the presence of spicules. 200 feet would be the necessary elevation in Java.

Spicules and other small organic remains are supposed to cause a local disease of horses' hoofs known as "chip-chip," which is much more prevalent in the coastal districts than inland.

In the sample from Isseka, W.A., the spicules are very abundant and range in length from 0.0664 to 0.1311 mms., with an average length of 0.056 mms. Isseka is fairly near the coast. In the Lake King samples the spicules are not nearly so abundant and are very much smaller.

Other organic remains include occasional diatom cases and radiolarian skeletons, but these are not nearly as common as the spicules.

B.—MODIFICATION OF FORM.

In the preceding section, the various forms developed by soil minerals have been summarised. Erosion has an important effect on the form of some minerals, *e.g.*, quartz, felspars, tourmaline, etc., but on others has little or no effect. Zircon in thin sections of rocks is just as likely to be rounded as euhedral, and therefore the occurrence of rounded zircon cannot, in most samples, be used as a criterion of prolonged erosion, and, moreover, rounded and euhedral forms usually occur together. However, the rounding of zircon may sometimes be due to erosion, as in the Esperance (W.A.) soils, in which large rounded zircons, quite unlike those found in igneous rocks, occur with well rounded quartz, tourmaline and a little felspar. Whether the material from which a soil has been formed has undergone long continued abrasion or not will be shown by the amount of rounding which the quartz grains have undergone. Sands from Esperance have been made the subject of a special investigation to determine the co-efficient of roundness as used by the Columbia University (4, p. 668) and the results tabulated.

Tourmaline grains often show a considerable degree of rounding, but here the original form of the grains must be considered, as the sections at right angles to the vertical axis are naturally more easily rounded than prismatic grains.

Garnets are very resistant to erosion, and no truly round grains have been observed, although half-round grains are fairly common.

The felspars wear easily and are often well rounded, while the associated quartz is angular to sub-angular. Chemical decomposition assists the rounding to a certain extent.

Augite and epidote (particularly the latter) are frequently rounded, whereas hornblende splits up into cleavage fragments and is never rounded, as far as observed. Magnetite and ilmenite appear to be rounded by erosion fairly readily, but the latter becomes coated with leucoxene which forms a protective blanket.

Rounding by erosion has some value in suggesting the past history of a soil. It has usually been considered that wind is a more efficient agency than water in the rounding of sand grains, but recent experiments have shown that this idea is erroneous (G. E. Anderson, Jour. Geol., Vol. 34, 1926, pp. 144-158). Phillips (Q.J.G.S. 1881) first gave prominence to the aeolian origin of "millet seed" grains, and from this the conception developed that the wear of sand grains by water was a slow process when compared with similar wear by wind. Water has been considered less effective than wind in the rounding of sand grains because of the surface tension of the film of water supposed to surround sand grains while submerged. This film, according to Goodchild ("Desert Conditions in Britain") serves as a cushion which prevents the grains actually coming in contact, or at least retards the force of impact and therefore reduces the rate of wear on the water-worn sand grains. It has been pointed out, however, that sand grains submerged in water cannot be regarded as surrounded by a film differentiated from the body of the water, and that the water will not prevent collision of the sand grains while submerged.

The rounding of grains by mechanical wear is an exceedingly slow process, and it does not appear likely that sand grains in a journey from the centre of a continent to the sea would experience sufficient wear to become rounded, and therefore sub-round and round grains must be of great age. The presence of a greater degree of rounding of grains, as well as a larger number of rounded grains, in recent dunes than on the beach is due to the selective sorting of the wind. Rounded grains are more easily rolled by the wind than the angular and flattish grains which are left on the beach or river flats. Submerged sand grains along the beaches are in constant motion and are free to collide, so that the beach presents the ideal situation for the rounding of sand grains. Dune sands move only occasionally and then only a fraction of one per cent. of the total volume of the dune. Rounding by wind can only occur when the ground velocity of the wind exceeds 10 miles per hour, which corresponds to about 36½ m.p.h. at a height of 130 feet above the ground.

IV.—MINERALOGICAL CHARACTERISTICS OF THE FINE SANDS FROM THE VARIOUS SOIL ZONES.

A.—Notes on the Tables.

The results of this investigation have been placed in two tables.

Table I. gives the locality, soil zone and minerals identified, together with the depth and catalogue numbers of the samples. The Eastern States samples are catalogued by the Waite Institute, while the numbers of the Western Australian samples refer to the Government Chemical Laboratory Catalogue. The catalogue numbers have been added so that if further information is published, it can be connected with that supplied in this paper.

Table II. shows the distribution and persistence of the minerals from the various localities. The approximate chemical composition (from Dana) has been added for convenience of reference.

B.—Soils from Pre-Cambrian Areas.

Practically all the samples from W.A. were from localities situated in areas underlain by Pre-Cambrian rocks. The known rock types represented in the samples are granite, basic igneous rocks (gabbro and dolerite), and

metamorphics (gneisses, etc.). The Pre-Cambrian area of W.A. is of wide extent, so that within its boundaries the following soil zones are found:—Mallee, Podsol, Brown Earth. There are also lateritic and alluvial soils, but only a few samples of these were available for examination. Several of the South Australian samples are from localities in the S.A. Pre-Cambrian area.

i.—*Mallee Zone Soils.*

Samples were obtained from Peak Charles, Lakes King, Kathleen, Brown, and Dajoing, W.A. Of these localities, Peak Charles and Dajoing are situated in granitic areas, the latter with small dolerite dykes (Dr. Simpson). Lakes King and Kathleen are also thought to be underlain by granite. Lake Brown, from the character of the heavy mineral content of the soil, is situated in an area occupied by metamorphic rocks. Nearly all these samples give only a very small quantity of heavy minerals. A section of the granite from Peak Charles was made, and it was found that ferromagnesians and accessories were very scarce, thus accounting for the scarcity of heavy minerals in the soil.

By referring to Table I., the estimated qualitative composition of the heavy fraction of the samples can be seen. The following is a short mineralogical description of the samples:—

Peak Charles, W.A. Lat. S. 33° 5′. Long. E. 121° 15′.

The heavy fraction is characterised by very small amounts of rounded epidote, small flakes of blue-green hornblende, and a few worn prismatic grains of zircon. Microperthite is conspicuous in the light fraction, while plagioclase and orthoclase are plentiful.

Lake King, W.A. About Lat. 33° 10′. Long. 119° 45′.

Heavy fraction is fine grained but of fairly large quantity, containing a good variety of minerals. Ilmenite and leucoxene are in approximately equal amounts; zircon occurs for the most part in large prismatic grains, a few of which are rounded; garnet in pale brown to colourless fragments is rather rare; topaz was doubtfully identified in two of the samples.

Lake Kathleen, W.A. About Lat. 33° 10′. Long. 119° 45′.

More plentiful heavy fraction than in the Lake King samples. Zircon present in small, rounded, brownish grains; tourmaline blue to brownish green; hornblende occurs in yellowish brown and blue-green, small, broken fragments. One grain of andalusite with dark inclusions was identified.

Lake Brown, W.A. Lat. 30° 50′. Long. 118° 28′.

The heavy fraction contained a great variety of minerals, including such typical metamorphic minerals as andalusite, staurolite, and sillimanite. Staurolite occurred mainly in small, broken grains, but in one of the mounts a small, very pleochroic, yellow-green cruciform twin was found. Zircon was fairly plentiful in brown, zoned crystals, somewhat rounded; also a few clear, colourless grains and one green, broken crystal with prisms and pyramid. The quartz in the light fraction contained zircon, rutile, and (?) apatite inclusions.

Dajoing, W.A. Lat. 30° 20′. Long. 118° 5′.

Zircon is the most interesting mineral of the heavy fraction and is present in several forms, the most noticeable of which are geniculate twins; zoned grains are common. Tourmaline is present in both rounded and prismatic grains. Hornblende is in blue-green fragments.

ii.—*Podsolised Zone Soils.*

Samples of podsols were obtained from Augusta, Jimperding, and Nornalup, W.A., and Mount Barker, S.A. The W.A. samples are all from localities situated in areas of metamorphic rocks, the country at Augusta and Nornalup being gneiss, while at Jimperding there is a large variety of rock types, including quartzites and gneisses invaded by basic dykes.

Augusta, W.A. Lat. 34° 17′. Long. 115° 9′.

The soil contained a large amount of heavy minerals of which the following were the most conspicuous: hornblende in dirty, brown-green, cleavage fragments; abundant garnet in large, broken, pale pink grains; ilmenite zircon, and epidote subordinate. Plagioclase accompanied the quartz in the light fraction.

Jimperding, W.A. Lat. 31° 30′. Long. 116° 45′.

The sample represents the panned concentrate from some small alluvial workings for gold. The following features were noted: ilmenite in clean grains, not much coated with leucoxene, and often showing metallic lustre; zircon either in small, zoned, brown grains, or in clear colourless grains, both types were worn prisms; tourmaline in sharp-edged, stumpy, grey prisms; rutile in yellow and red, rounded stumpy prisms. The minerals of the light fraction were not determined.

Nornalup, W.A. Lat. 35° 0′. Long. 116° 30′.

The soil contained a fair amount of heavy fraction, but yielded only a few species. Zircon is very abundant in many types, the most plentiful being colourless, rounded prisms; hornblende in brown-green fragments, some of which are very light in colour; ilmenite and leucoxene in about equal amounts with a little garnet. In the light fraction orthoclase accompanies the quartz.

Mount Barker, S.A. Lat. 35° 5′. Long. 138° 58′.

The heavy fraction consists of tourmaline in abundant, brown, very pleochroic prisms with inclusions; zircon in colourless prismatic and rounded grains; rutile abundant in yellow acicular crystals and rounded, red grains; a little augite, hornblende, muscovite, epidote, and ? sillimanite. The light fraction is made up of quartz, orthoclase and plagioclase.

iii.—*Soils from the Brown Earth Zone.*

Samples of soil from the Brown Earth Zone were obtained from Narrogin, Katanning and Isseka, W.A., and Auburn, S.A. Two samples were obtained from Narrogin, one was above a basic rock, probably a gabbro, while the other was over granite similar to that found in the Katanning district. The soil from Isseka was overlying a basic dyke (dolerite), but microscopic examination showed that it was mixed with soil from adjacent garnet gneiss (see map, 5).

Narrogin, W.A., Lat. 32° 55′. Long. 117° 12′.

The heavy fraction of the soil weathering from granite is noticeable for the abundant zircon; ilmenite is twice as plentiful as leucoxene; a little epidote is present. Orthoclase and plagioclase are both present in the light fraction.

The soil from the basic rock differs from the granitic soil in the greater abundance of epidote, and the presence of leucoxene only in incipient development on a few of the ilmenite grains. Zircon is not abundant and occurs in small prisms with dusty inclusions. Abundant augite and hornblende (dirty green fragments).

Katanning, W.A. Lat. 33° 38′. Long. 117° 35′.

The soil overlies granite, and the main characteristics of the heavy fraction are found in the well-developed leucoxene, plentiful zircon of two types, one clouded with inclusions, the other clear; both types in rounded prismatic crystals. Rutile, hematite and garnet are the remaining heavy minerals. Orthoclase and quartz make up the light fraction.

Isseka, W.A. About Lat. 28° 40′. Long. 114° 45′.

The heavy fraction is noticeable for the small number of species it contains. Ilmenite is the most abundant mineral, followed by pale pink garnet (from gneiss) and brownish weathered augite. The sample resembles that of a basaltic soil, this being accounted for by the similar mineralogy of basalts and dolerites.

Auburn, S.A. Lat. 33° 47′. Long. 151° 2′.

Ilmenite and leucoxene present in practically equal amounts, with well-developed rutile. Magnetite abundant; tourmaline occurs in slender, grey prisms; zircon subordinate; muscovite and biotite in the usual flat plates. Quartz, orthoclase and plagioclase form the light fraction.

iv.—*Lateritic Soils.*

Only two soils of this type have been examined, one from Kulikup, in the Boyup Brook district of W.A., and the other from Kuitpo, S.A. The Kulikup sample was collected on a laterite ridge which has been broken down by long-continued weathering. The soils on either side of the ridge, which is formed by an underlying fine-grained basic dyke, are podsolised soils formed from granite.

Kulikup, W.A. About Lat. 33° 45′. Long. 116° 30′.

There is not a very large amount of heavy fraction and it contains few species. Of these, ilmenite, leucoxene and rutile are abundant, and present in approximately equal amounts. Zircon is in clear, acicular prisms, some of which are rather worn.

Kuitpo, S.A. Lat. 35° 12′. Long. 138° 48′.

The heavy fraction contains a large variety of minerals of which magnetite is very abundant. Ilmenite and leucoxene in about equal amounts; zircon plentiful in small prismatic crystals; tourmaline abundant in pleochroic blue to violet grains, a few brown. Muscovite, epidote and hornblende subordinate. Anatase was doubtfully identified in one sample.

v.—*Alluvial Soils.*

Samples of alluvial soils, the material of which was derived from Pre-Cambrian rocks, were obtained from Alexandra Bridge, Donnybrook, W.A., and Glen Osmond, S.A. The sample from Renmark, S.A., is included here for convenience. The W.A. samples were collected close to rivers distributing the disintegration products of the Pre-Cambrian area.

Donnybrook, W.A. Lat. 33° 0′. Long. 116° 0′.

The heavy fraction is characterised by abundant hornblende in dirty, brown-green fragments, ilmenite, rutile and muscovite; tourmaline subordinate in rather short, stumpy grey prisms.

Alexandra Bridge, W.A. About Lat. 34° 15′. Long. 115° 10′.

Hornblende abundant in dirty, brown-green fragments; ilmenite plentiful; zircon fairly common in prismatic crystals, somewhat rounded; tourmaline subordinate.

Renmark, S.A. Lat. 34° 15′. Long. 140° 30′.

The sample is from a river terrace and contains a fairly abundant heavy fraction. The most noteworthy features are: presence of kyanite and sillimanite, the abundance of tourmaline and the approximately equal amounts of ilmenite and leucoxene, with subordinate rutile and a little biotite. Plagioclase is present in the light fraction.

Glen Osmond, S.A. Lat. 34° 57′. Long. 138° 38′.

The soil is described as a "red-brown loam; wash from Pre-Cambrian." The heavy fraction is characterised by abundant tourmaline in pleochroic pink to green prisms, and also in blue fragments; zircon rather subordinate in small, brown, zoned prisms; leucoxene in excess of ilmenite, with rutile fairly common. Some samples contain andalusite and a little garnet. The micas are well represented. In some samples microcline and microperthite are found in the light fraction.

vi.—*Esperance (W.A.) Soils.*

Three profile samples of a soil at Esperance were examined. Chemically, these soils have all the characteristics of lateritic soils (oral communication, Teakle and Southern; also 24, p. 79), but microscopically appear more like sand dunes. Perhaps the sand has been partly derived from a broken down laterite, the rounding being produced as a result of long continued shifting by wind. Possibly the original "laterite" was formed over an argillaceous sandstone (W. G. Woolnough, Geol. Mag., March, 1930), but from later information it appears that granite is the principal rock in the area.

Esperance, W.A. Lat. 33° 52′. Long. 121° 55′.

The heavy fraction is very small and consists of well-worn grains of brown tourmaline, zircon, limonite, ilmenite and leucoxene. The light fraction consisted principally of well-rounded quartz grains, often filled with slender rutile rods. A little rounded orthoclase accompanies the quartz.

The soil appears to be a dune sand, as the worn quartz grains testify to a second cycle of wear by water and wind.

Esperance Sands.—These sands from the coast inland were examined by the method outlined by F. A. Burt (Jour. Geol. 1929, p. 668). The co-efficient of roundness was worked out by examining the quartz grains under the microscope, and dividing them into the following types:—round, sub-round, half-round, sub-angular, angular. The total number of grains of each type is multiplied by 128, 32, 8, 2 and 1, respectively, the products added, and then divided by the total number of grains examined. Only the quartz grains were examined in order to make the results more uniform.

The Esperance sands consist of clear, colourless quartz, with a noticeable amount of felspar, very subordinate tourmaline, and a little zircon. The quartz often contains sagenite webbing of rutile, some grains enclosing a network of tiny rutile rods.

For comparison, the quartz grains of a dune sand from Bunbury, near the beach, and a sample of normal granitic soil from Peak Charles were examined.

Sample.	Round.	Sub-round.	Half-round.	Sub-angular.	Angular.	Total No. grains.	Coeff. round.
Esperance I. ...	17	120	260	147	7	551	15·24
Esperance II. ...	73	173	284	183	4	717	24·44
Esperance III. ...	94	132	378	197	47	848	23·25
Esperance IV. ...	94	176	297	167	21	755	27·01
Esperance V. ...	128	193	336	109	1	767	33·21
Esperance VI. ...	124	156	358	108	9	755	31·72
Bunbury (dune sand)	42	41	147	88	7	325	24·19
Peak Charles (granitic)	6	28	109	144	78	375	7·74

From the table it will be seen that the coefficient of roundness for the Esperance sands is very much higher than that of a normal granitic soil. The samples apparently approximate to dune sands. Comparison with the figures quoted by Burt shows that these sands would fall into the beach sand group, but this classification cannot be accepted as final, because the standard of grain shape used in America may differ from the standard arbitrarily set up for the purposes of this examination.

C.—BASALTIC SOILS.

Only one basaltic soil from W.A. has been examined. This was the overburden in a small quarry about six miles south of Bunbury. Basaltic soils from the Eastern States ranging from black earths, through red loams, to dark brown soils have been examined. The most noteworthy features of all the samples were the smallness of the grain size, and the large amount of heavy fraction, which often appeared to make up about half the fine sand. The fine sands are all very similar mineralogically, so that brief descriptions only will be given.

Forth, Tas. Lat. 41° 15′. Long. 140° 45′. Red loam.

Clifton, Q. Lat. 27° 38′. Long. 147° 7′. Red loam and black earth.

Meteor Downs, Q. Lat. 24° 21′. Long. 148° 17′. Black earth.

The heavy fractions are made up principally (probably 90 per cent.) of ilmenite with a little magnetite. Leucoxene is absent, but rutile is conspicuous. Augite, tourmaline, and zircon are subordinate.

Lyonville, Vic. Lat. 37° 20′. Long. 144° 15′ (about).

Differs from the above samples by the larger amount of zircon in small, rounded and acicular grains, some containing inclusions. A little biotite is present. The light fraction consists of orthoclase, plagioclase, and quartz.

Merriwa, N.S.W. Lat. 32° 8′. Long. 150° 20′. Black earth.

Leucoxene is absent, the ilmenite : rutile ratio is 9 : 5. Zircon is common in stout, prismatic crystals and broken fragments. Tourmaline, where present, is in slender prisms.

Mirrool, N.S.W. Lat. 34° 15′. Long. 146° 15′. Dark brown soil.

Leucoxene is present, but not abundant, while there is a corresponding decrease of rutile, which occurs in reddish brown, prismatic grains and geniculate twins. Tourmaline common in large, rounded grains. Zircon fairly abundant.

Bunbury, W.A. Lat. 33° 18′. Long. 115° 38′. Reddish brown soil.

Differs from the Eastern States basaltic soils only in the presence of a little brown garnet, epidote and hornblende. Brown tourmaline is common.

On referring to Table I. the association of ilmenite and rutile and the absence of leucoxene in nearly all the basaltic soils is immediately noticed.

The absence of leucoxene in basaltic soils is of great interest since it shows either that:

> The soils are too young for leucoxene to develop;

or that:

> The conditions for the conversion of ilmenite to leucoxene are unfavourable.

The titanium minerals, ilmenite, anatase, rutile, brookite, sphene and leucoxene, form a series, and if conditions are favourable transformations may take place from one mineral to another. (Clarke, Data of Geochemistry, 1924, p. 355.)

Anatase is considered to be authigenic, *i.e.*, generated in situ at the expense of the other titanium minerals. Rutile may be both allogenic and authigenic, and similarly with sphene and leucoxene. Brammall and Harwood (3, p. 24) have suggested that the authigenic occurrence of anatase and brookite may be due to the alteration of biotite under sour water conditions. By boiling biotite with HCl, the biotitie is bleached and some of the original titania removed. Thus the original fresh biotite contained 1.77 per cent. TiO_2, the partially bleached 1.23 per cent. TiO_2 and the completely bleached residue, 0.61 per cent. TiO_2.

On decomposition the biotite may form a colloidal complex of titania and silica, and these may disengage themselves and become crystalline, the titania forming anatase, while the silica extends and repairs quartz grains and forms new ones. J. van Baren mentions and figures authigenous quartz crystals (1, p. 37; plate 1, figs. 5 & 6).

Ilmenite may alter to granular anatase under similar conditions. The instability of biotite (derived from parent rocks) under certain conditions, has led to the idea that a large number of transparent titanium minerals, such as anatase, may be due to the presence of sufficient biotite in the parent rocks. High porosity and ill-graded sediments favour the development of anatase.

Leucoxenic alteration is at a maximum in coarse sediments. The presence of lime is essential. Where lime is absent or at a minimum, especially in an iron-rich environment, the ilmenite-rutile-anatase-brookite tendency is predominant.

Thus there may be a relationship between the reaction of a soil and the ilmenite-leucoxene ratio.

In the basaltic soils of the Eastern States no leucoxene is developed, but rutile is always present (in the samples examined). This association suggests that in the absence or minimum amount of lime, rutile develops

instead of leucoxene. Probably some of the rutile is allogenic. The explanation of the lack of leucoxene in all the samples, except one, may be that the weathering processes have not been continued for a sufficient length of time for the liberation of lime from the ferromagnesians, which would combine with titania to form leucoxene. The samples from Lake Brown and Lake King, W.A., have high pH values (24, pp. 77-78, table), and there are approximately equal amounts of ilmenite and leucoxene.

If lateritic soils owe their acidity to previous climatic conditions, it seems difficult to account for the presence, in both the samples examined, of ilmenite, leucoxene, rutile and sphene, and of anatase in one. An acid environment indicates lack of lime, which suggests that the ilmenite-rutile tendency would be dominant. Sphene and leucoxene indicate neutral or alkaline environment. Sphene appears to be an unstable species in sediments. It may be formed originally in the soil, but owing to chemical instability or unfavourable conditions the sphene-rutile-ilmenite tendency may be promoted. There is too little evidence so far to show whether this would account for the association or not. Perhaps only long continued weathering is indicated with very thorough liberation of lime from the ferromagnesians and original lime-containing minerals.

Summarising, therefore, it appears that—

(a) from the association of the different members of the titanium series, it may be possible to give some indication of the present reaction of a soil and to offer some suggestions as to its mode of development.

(b) The ilmenite-leucoxene ratio alters with age in favour of the latter.

(c) The ilmenite-leucoxene ratio will be of importance in the study of soils from the point of view of past history and nature of weathering, when the matter has been more fully investigated.

D. TERTIARY SOILS.

i.—*Pleistocene Volcanic Ash Soil.*

The sample is from *Mt. Gambier*, S.A., Lat. 37° 51′, Long. 138° 58′, and has a distinctive mineralogical character in the abundant development of anatase, a titanium mineral which, as already mentioned, appears to form in situ where lime is at a minimum. Anatase occurs in flat crystals with bevelled edges and in bunches of small acicular crystals, some of which may be brookite a mineral identical in composition with anatase. Of the remaining minerals of the heavy fraction, leucoxene is slightly more abundant than ilmenite while zircon and augite are subordinate. The light fraction does not give any distinctive features.

ii.—*Tertiary Mallee Soils.*

Samples of soil from the Mallee zone were obtained from three localities in the Eastern States. They are described here for convenience, as there was no information given of the geology of the districts in which they occur.

Yurgo, S.A. Lat. 35° 10′. Long. 140° 5′ (approx.).

The heavy fraction contains a fair variety of minerals, the most abundant of which are tourmaline, ilmenite, rutile, and hornblende. Biotite, augite and zircon are subordinate, the latter present in clear, acicular crystals, some rounded. Plagioclase occurs in the light fraction.

Roto, N.S.W. Lat 33° 11′. Long. 145° 30′.

The heavy fraction contains only a few species, of which brown tourmaline is the most abundant. Ilmenite and leucoxene present in the ratio of 6 : 4. Zircon and amphibole are subordinate. The light fraction consists of quartz and orthoclase.

Coomealla, N.S.W. Mildura district.

The heavy fraction contains a large variety of minerals of which blue and brown tourmaline is the most abundant, muscovite and zircon common, the latter in stout, prismatic crystals. Ilmenite : leucoxene as 5 : 8. Rutile, hornblende and garnet are subordinate. Light fraction consists of quartz orthoclase and plagioclase.

E.—Significance of Variation of Form and Colour of Soil Minerals.

In the petrography of sedimentary deposits it has long been known that certain minerals, generally with characteristic colours and forms, are found in definite horizons (2, p. 26; 25; 26), and in oil-field mineralogical correlation the same has been found, though it is noted as a factor minor in importance to the actual mineral associations. Recently work has been done on the correlation of igneous rock types by means of characteristic accessory minerals (10, p. 235). The results seem to show that most of the accessory minerals are of little use for correlation purposes, and that zircon is the most reliable accessory. This fact seems to be borne out by the occurrence in soils of zircons of special types. The samples from Lake Brown contain a very large proportion of brown zoned zircons. In other localities in W.A. the zircons are clear and colourless with few inclusions. Again, occasional zircon twins have been found, and these only in the soil from Dajoing, W.A. A great deal of careful work is necessary before data of value could be obtained, but the question seems worth further investigation.

Hornblende is a mineral which has various colours. The very blue-green variety may be characteristic of certain rocks while the more common, brownish-green variety will have less value for correlation purposes. Colourless amphibole occurs in a few soils, while it is absent from the majority.

Tourmaline is a common mineral of soils and usually occurs in brown to grey, pleochroic fragments. In a few samples the predominating tourmaline is blue, while pinkish purple tourmaline has also been found. The blue variety may indicate a particular kind of parent rock.

The forms and colours developed by the minerals enumerated above will doubtless be of great value for diagnostic purposes when further work has been carried out and our knowledge of the accessories of the parent rocks increased.

In order to obtain the desired information about the accessory minerals of rocks, it would be necessary to examine crushed rocks, and not rock sections, because the majority of the accessories would undoubtedly be missed in the sections, and in any case, several characteristic features would be lost.

No investigations of this kind have yet been carried out in W.A. and too little is known of the rock types, so far, for any conclusions to be drawn, but an interesting line of investigations is suggested.

F.—SUMMARY.

1. With the exception of anatase, only common rock forming minerals have been identified, but the results agree with those obtained for the U.S.A. (8, p. 292), Dutch and Javanese soils (1, p. 67).

2. Quartz, felspar, ilmenite, leucoxene, rutile, hornblende, augite, tourmaline, and zircon are the minerals of most common occurrence in Australian soils.

3. The ilmenite-leucoxene ratio and the association of the titanium minerals are important.

4. The variation of form and colour of soil minerals may be of use in limiting and diagnosing soil types.

5. Sponge spicules occur in practically every soil examined; other organic remains are not nearly so plentiful.

6. The degree of rounding of the grains, particularly quartz, is important as an aid to distinguishing between sedentary and transported soils.

V.—CONCLUSIONS.

1. The mineral assemblage of the fine sand fractions of soils is strongly influenced by the composition of the underlying rock.

2. The amount and quality of the light fraction is an index of the fertility of the soil.

3. The separation of the heavy minerals of soils may be a quick and useful means of geological mapping where outcrops are scarce or lacking.

4. At present, this method of soil examination does not appear to be of much value for description and correlation purposes. This may be due to the fact that, so far as the Western Australian samples are concerned, too little is known of the detailed geology of the localities, most of which are in the Pre-Cambrian areas. With well defined small areas of known rock types more useful information would be obtained. The basaltic soils examined all appear very similar mineralogically, and show that where similarities undoubtedly exist, they will be readily shown by a microscopic examination. Such an examination of soils will add information to that supplied by mechanical and chemical analyses.

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TABLE I. SHOWING LOCALITIES, GEOLOGY, SOIL ZONE, DEPTH OF SAMPLES, CATALOGUE NUMBERS AND MIN[illegible]ALOGY [illegible] SANDS EXAMINED.

Sample	Geology	Soil Zone	Cat. No.	Depth	Species present	Species present
[illegible] W.A.	[illegible]	[illegible]		[illegible]	4	10
[illegible] W.A.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11
Do	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12
Do	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13
Do	[illegible]	[illegible]	[illegible]	[illegible]	6	[illegible]
Lake [illegible] W.A.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10
Do	[illegible]	[illegible]	[illegible]	[illegible]	7	12
Do	[illegible]	[illegible]	[illegible]	[illegible]	7	12
Do	[illegible]	[illegible]	[illegible]	[illegible]	6	11
Lake King W.A.	[illegible]	[illegible]	[illegible]	[illegible]	8	13
Do	[illegible]	[illegible]	[illegible]	[illegible]	5	10
Do	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11
Do	[illegible]	[illegible]	[illegible]	[illegible]	6	11
Lake Kathleen W.A.	[illegible]	[illegible]	[illegible]	[illegible]	9	14
Do	do	do	[illegible]	[illegible]	10	15
Do	do	[illegible]	[illegible]	[illegible]	8	13
Do	do	[illegible]	[illegible]	[illegible]	7	12
Lake Brown W.A.	[illegible]	[illegible]	[illegible]	[illegible]	14	19
Do	[illegible]	[illegible]	[illegible]	[illegible]	13	17
Do	[illegible]	[illegible]	[illegible]	[illegible]	14	20
Do	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18
Do	[illegible]	[illegible]	[illegible]	[illegible]	12	17
Do	do	[illegible]	[illegible]	[illegible]	11	16
[illegible] W.A.	[illegible]	[illegible]	[illegible]	[illegible]	7	[illegible]
Do	[illegible]	[illegible]	[illegible]	[illegible]	7	11
[illegible] W.A.	[illegible]	[illegible]		[illegible]	5	8
[illegible] W.A.	[illegible]	[illegible]			10	10
[illegible] W.A.	[illegible]	[illegible]	[illegible]	[illegible]	9	[illegible]
Do	[illegible]	[illegible]	[illegible]	[illegible]	6	[illegible]
Do	[illegible]	[illegible]	[illegible]	[illegible]	9	[illegible]
Do	[illegible]	[illegible]	[illegible]	[illegible]	7	11
[illegible]					11	15
[illegible] S.A.	[illegible]	[illegible]	[illegible]	[illegible]	5	8
[illegible] W.A.	[illegible]	[illegible]		[illegible]	7	11
[illegible] W.A.	[illegible]	[illegible]		[illegible]	[illegible]	9
[illegible] W.A.	[illegible]	[illegible]		[illegible]	4	8
[illegible] W.A.	[illegible]	[illegible]		[illegible]	9	14
[illegible] S.A.	[illegible]	[illegible]			[illegible]	9
[illegible] W.A.	[illegible]	[illegible]			14	18
[illegible] S.A.	[illegible]	[illegible]	[illegible]	[illegible]	7	11
Do	[illegible]	[illegible]	[illegible]	[illegible]	8	10
Do	do	do	[illegible]		6	9
[illegible] W.A.	[illegible]	[illegible]		[illegible]	7	[illegible]
[illegible] W.A.	[illegible]			[illegible]	10	14
[illegible] S.A.		[illegible]	[illegible]	[illegible]	9	14
[illegible] S.A.	[illegible]	[illegible]	[illegible]	[illegible]	8	13
Do	[illegible]	[illegible]	[illegible]	[illegible]	9	13
Do	[illegible]	[illegible]	[illegible]	[illegible]	10	15
Do	[illegible]	[illegible]	[illegible]	[illegible]	11	16
Do	[illegible]	[illegible]	[illegible]	[illegible]	11	15
Do	[illegible]	[illegible]	[illegible]	[illegible]	11	18
Do	[illegible]	[illegible]	[illegible]	[illegible]	5	8
Do	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8
[illegible] W.A.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7
Do	[illegible]	[illegible]	[illegible]	[illegible]	8	13
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4	9
Do	[illegible]	[illegible]	[illegible]	[illegible]	4	8
[illegible]					4	8
Clifton Q.	[illegible]	[illegible]	[illegible]	[illegible]	5	8
Do	[illegible]	[illegible]	[illegible]	[illegible]	5	9
Do					4	7
Clifton Q.	[illegible]	[illegible]	[illegible]	[illegible]	4	7
Do	[illegible]	[illegible]	[illegible]	[illegible]	5	9
Do	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8
Meteor Downs [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	12
Do			[illegible]	[illegible]	5	10
Do			[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]	5	10
Do					[illegible]	9
[illegible]				[illegible]	6	11
[illegible] N.S.W.	[illegible]	[illegible]	[illegible]	[illegible]	6	10
Do				[illegible]	5	9
Do		[illegible]	[illegible]	[illegible]	7	12
[illegible] N.S.W.			[illegible]	[illegible]	8	11
Do				[illegible]	6	10
[illegible] W.A.			[illegible]	[illegible]	[illegible]	[illegible]
[illegible] S.A.	[illegible]				9	13
[illegible]			[illegible]	[illegible]	6	8
[illegible] S.A.	[illegible]	[illegible]	[illegible]	[illegible]	8	[illegible]
[illegible] N.S.W.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] N.S.W.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Do	[illegible]				[illegible]	[illegible]

TABLE II.—SHOWING DISTRIBUTION AND PERSISTENCE OF SOIL MINERALS.

Mineral.	Chemical Composition.	Alexandra Bridge, W.A.	Auburn, S.A.	Augusta, W.A.	Bunbury, W.A.	Clifton, Q.	Coomealla, N.S.W.	Dajoing, W.A.	Donnybrook, W.A.	Esperance, W.A.	Forth, Tasmania.	Glen Osmond, S.A.	Issoka, W.A.	Jimperding, W.A.	Katanning, W.A.	Kuitpo, S.A.	Kulikup, W.A.	Lake Brown, W.A.	Lake Kathleen, W.A.	Lake King, W.A.	Lyonville, Victoria.	Merriwa, N.S.W.	Motoor Downs, Q.	Mirrool, N.S.W.	Mount Barker, S.A.	Mount Gambier, S.A.	Narrogin, W.A.	Nornalup, W.A.	Peak Charles, W.A.	Renmark, S.A.	Roto, N.S.W.	Yurgo, S.A.
1. Amphibole (colorless)	$R \cdot SiO_3 \cdot R$ = Ca, Mg, Fe, Mn. ...						—				—	—												—						—	—	
2. Anatase...	TiO_2.															—										—						
3. Andalusite	Al_2O_3. SiO_2.											—						—	—													
4. Augite	(Ca, Mg.) Si_2O_6 + (Mg, Fe), (Al, Fe). SiO_6.							—			—		—	—				—	—	—	—	—	—	—	—	—	—	—				—
5. Biotite	$(H, K)_2$. $(Mg, Fe)_4$. $(SiO_4)_4$. ...		—									—						—			—									—		—
6. Chlorite	Hyd. Sil. Al, Fe, Mg.																	—														
7. Epidote	H_2O. 4CaO. $3(Al, Fe_3)_2O_3$. $6SiO_2$. ...			—	—					—		—		—		—		—							—		—		—	—		
8. Garnet	3RO. R_2O_3. $3SiO_2$. R = Ca, Mg, Fe, Mn. R = Al, Fe, Cr, Ti.	—			—	—	—	—	—			—	—	—	—			—	—	—								—				
9. Hematite	Fe_2O_3.										—			—	—	—	—										—					
10. Hornblende	R. SiO_3.	—		—	—		—	—	—			—		—		—		—	—	—					—	—	—	—	—	—		—
11. Ilmenite	FeO. TiO_2.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
12. Kaolinised material ...	? Hyd. Al. Sil.		—			—	—	—		—	—	—	—		—	—	—	—	—	—	—	—	—			—	—	—	—	—		—
13. Kyanite	Al_2O_3. SiO_2.																													—		—
14. Leucoxene	*See* Sphene.		—		—		—	—		—		—		—	—	—	—	—	—	—		—		—	—	—		—		—	—	—
15. Limonite	Fe_2O_3. H_2O.					—				—	—	—									—	—						—				
16. Magnetite	FeO. Fe_2O_3.		—													—		—														
17. Microcline	K_2O. Al_2O_3. $6SiO_2$.											—							—	—												
18. Microperthite	Orthoclase-Albite.				—							—						—		—									—			
19. Monazite	(Ce, La, Di). PO_4.																	—														
20. Muscovite	(H, K). $Al(SiO_4)$.		—				—		—			—				—		—	—						—							
21. Orthoclase	K_2O. Al_2O_3. $6SiO_2$.	—	—		—	—	—	—	—	—	—	—	—		—	—	—	—	—	—	—	—		—	—	—	—	—	—	—	—	—
22. Plagioclase	$(Na_2, Ca)O$. Al_2O_3. $nSiO_2$.		—	—		—	—				—	—						—		—	—	—	—	—	—				—	—		—
23. Pleonaste	(Mg, Fe)O. Al_2O_3.				—													—														
24. ?Pyrite	?FeS_2.		—					—								—																
25. Quartz	SiO_2.	—	—	—	—	—	—	—	—	—	—	—	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
26. Rutile	TiO_2.	—	—		—	—	—	—	—		—	—		—	—	—	—	—	—	—	—	—	—	—	—		—	—		—		—
27. Sillimanite	Al_2O_3. SiO_2.											—				—		—						—				—		—		
28. Sphene	CaO. TiO_2. SiO_2.	—														—		—	—	—					—			—		—	—	
29. Staurolite	H_2O. 2FeO. $5Al_2O_3$. $4SiO_2$.																	—														
30. ? Topaz	?$Al(F, OH)_2$. $AlSiO_4$.																	—		—												
31. Tourmaline	H_9Al_3. $(B, OH)_2$. Si_4O_{19}.	—	—		—	—	—	—		—	—	—		—		—		—	—	—	—	—	—	—	—			—		—	—	—
32. Zircon	ZrO_2. SiO_2.	—	—	—	—	—	—	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
33. Spicules...	SiO_2. nH_2O.		—	—	—	—	—	—	—		—	—	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—			
	Total number of Minerals ...	9	14	7	13	11	14	13	8	9	13	21	8	10	10	18	9	26	16	17	12	12	9	12	14	10	11	15	10	16	8	13

GENERAL INDEX.

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GENERAL INDEX—*continued.*